Finnra

Roundabouts and heavy vehicles

Finnra
Reports

13/2000

Helsinki 2000

Finnish National
Road Administration
Traffic and Road
Engineering

Finnra Reports
13/2000

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Finnish National
Road Administration

Helsinki 2000

ISSN 0788-3722
ISBN 951-726-624-3
TIEL 3200602E

Oy Edita Ab
Helsinki 2000

The Publication is sold by
Finnra/Library
Telefax Int.+358 (0)204 44 2652
http//:www.tielaitos.fi/libr.htm

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RAHMAN, Hafizur, ELORANTA, Anu, ERNVALL, Timo: Roundabouts and heavy vehicles. Helsinki 2000. Finnish National Road Administration (Finnra), Traffic and Road Engineering, Finnra reports 13/2000, 66 p. + apps. ISSN 0788-3722, ISBN 951-726-624-3, TIEL 3200602E

Subject class 21, 31

Key words roundabout, heavy vehicle, speed, vehicle path

ABSTRACT

Roundabouts have become a subject of great interest in the 1990s. Modern roundabouts differ from traditional traffic circles in that they force the vehicles to slow down. The behaviour of heavy vehicles in traffic is different compared to light vehicles because of their size and operation. Many large commercial vehicles are unable to negotiate small radius turns.

Problems experienced at roundabouts by drivers of heavy vehicles include insufficient vehicle path curvature, high and sharp-edged kerbing on the truck apron etc. The main aim of this study was to recognise problems and investigate solutions to the problems of heavy vehicles at the roundabouts.

Data was collected in both winter and summer on 10 roundabouts chosen from the Finnish main road network. Data collection included recording vehicle speeds, recording vehicle paths, recording geometric parameters and video recording of each individual vehicle. Statistical analyses have been carried out to compare the recorded vehicle data with the geometric parameters. Vehicle path and speed analyses were performed and considered against the straight path through the selected roundabouts.

Vehicle paths differed significantly between in summer and winter at most of the roundabout, being generally closer to the kerb of the central island in winter than in summer. The path taken by the vehicle depends on radius of the curvature and the width of the circulatory carriageway. The smaller the curvature and width of the circulatory carriageway, the closer the vehicle path is to the central island. According to the observations of the roundabouts studied, a radius of curvature below 35 metres can cause difficulties for truck and trailer combinations.

The average approach speeds at 50 metres before the entry to the roundabout of trucks and buses were 37 - 45 km/hour, and the corresponding values for trucks with trailers were 35 - 41 km/hour. The vehicle speeds on entering the roundabout were found to be as high as half of the approach speeds. The speeds at entry were affected by the entry deflection, and entry speeds decreased when the entry deflection increased. The correlation's between these two factors were stronger in summer conditions than in winter.

On the circulatory carriageway of the roundabout vehicle speeds fluctuated between 20 and 26 km/hour in the case of trucks and buses and 14 - 22 km/hour in the case of truck and trailer combinations. On the roundabouts were average vehicle speeds were lower than 20 km/hour, geometry of the roundabouts were less relevant and caused extra difficulties for heavy vehicles. The speed on the circulatory carriageway was directly correlated with the width of the circulatory carriageway and the curvature of the vehicle path. In the roundabouts studied the central island diameters were 16 - 40 metres. For vehicles driving straight across the roundabout the bigger the diameter of the central island the lower the speed on the circulatory carriageway. Speeds at the exit of the roundabout, where drivers usually start to accelerate depended on the speeds on the circulatory carriageway. The average speeds at the exit were generally 2-5 km/hour higher than the average speeds of vehicles on the circulatory carriageway.

The study shows that compared to signal-controlled junctions, fewer vehicles had to stop before the roundabout. Of the 881 heavy vehicles studied, only 68 had to stop while 104 had reduce their speed under 14 km/hour as they entered the roundabout. Vehicles from all directions are able to pass through a roundabout more comfortably without any unnecessary stoppage. Roundabouts generally will reduce the total delay and will lead to higher capacity.

Drivers of heavy vehicles seem to be generally satisfied with roundabouts. The most serious difficulties are experienced by drivers of module combinations and other track and trailer combinations, whereas drivers of buses and trucks without trailers have fewer problems.

For bus drivers, the behaviour of other drivers at roundabouts seems to be the most serious problem, while for trucks without trailers the biggest problem is the slippery road surface in winter. Design aspects, such as kerbs and restricted carriageway width are some of the biggest problems for drivers of module combinations and other truck and trailer combinations. Hitting kerbs can result in punctured tyres.

Most drivers seem to prefer roundabouts to signal-controlled junctions. Those with the opposite view also have a more negative attitude towards roundabouts in general. However, as drivers acquire more experience, their attitudes towards roundabouts tend to become slightly more positive.

FOREWORD

This report discusses roundabouts from the viewpoint of drivers of heavy vehicles. The most important factors considered are vehicle speeds, vehicle paths and geometry of roundabouts. A total of ten roundabouts in different parts of Finland are included, eight of them are located on the main road network.

This report was commissioned by the Traffic and Road Engineering Unit of the Finnish National Road Administration and was carried out at the Road and Transportation Laboratory of the University of Oulu in northern Finland. Ari Liimatainen has acted as liaison for the Finnish National Road Administration.

The report was prepared by engineering student Hafizur Rahman and is a summary of his thesis originally written in English. The report also includes a survey in which drivers of heavy vehicles were asked to give their opinions about roundabouts. The material from the survey was processed by engineering student Anu Eloranta, while Professor Timo Ernvall from the University of Oulu provided expert assistance.

Kari Talsta and Teuvo Ryynänen from the University of Oulu also took part in planning and implementing the field surveys.

Helsinki, March 2000

Finnish National Road Administration
Traffic and Road Engineering

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KEY WORDS

Mean speed = Arithmetic mean of the observed data.

Standard deviation (stdev) = Standard deviation of the observed data.

V85 = 85th percentile speed.

Entrance point = A selected point at the entrance of the roundabout.

Exit point = A selected point at the exit of the roundabout.

Approach speed = Speeds 50 meters before the entrance point of the roundabout.

Category 1 vehicles = Trucks and buses.

Category 2 vehicles = All truck and trailer combinations.

1 BACKGROUND AND AIM OF THE STUDY

Modern roundabouts are completely different compared to traditional traffic circles. Improvements in design and regulations have made them safer than conventional junctions. Modern roundabouts eliminate dangerous accident types like head-to-head collisions. At the roundabout, injury accidents decrease about 50% or even more than those of at-grade intersection /1/. Roundabouts are effective because the design criterion forces the vehicles to slow down. Another important factor is that, there are few conflict points than those of at-grade intersection /2/. In Swedish 'before and after' study, the median of the decrease of accident risk is 35% for all road users /3/.

The Finnish National Road Administration (Finnra) interested in the new type of roundabout as a safer and fluent intersection from the beginning of 1990s. They have already built over 120 new roundabouts in the 1990s /1/.

The proportion of heavy vehicles in Finnish traffic flow fluctuates between 10-15% on an average. The behaviour of heavy vehicles in traffic is different from that of light vehicles because of their size and operation. Heavy vehicles have operating capabilities that are inferior to those of light vehicles. Many large commercial vehicles are unable to negotiate small radius turns and compelled to slow down /5/. So when a heavy vehicle approaches to an intersection its driving characteristics are completely different from, for example a passenger car.

The driver's opinions considering new roundabouts have studied in Finland in 1995 for heavy vehicles and their included four modern roundabouts. About 60 percent of drivers of heavy vehicles replied that roundabouts made their driving easier. The size of the central island was satisfactory to 60 percent of drivers. A greater disadvantage was the small size of the roundabouts. The 91 percent of heavy vehicles' drivers preferred a wider circulatory carriageway and 65 percent preferred a bigger radius. The study recommends that, for manoeuvring heavy vehicles, the minimum diameter of the central island should be at least 20 meters. Also another important factor is the width of the circulatory carriageway. According to the user opinions, if there is special transportation route through the roundabout, it should be taken into consideration in designing roundabout /19/.

According to the opinions of the drivers of heavy vehicle, there are following problems in the roundabouts:

I. Insufficient radius/diameter for heavy vehicles.

II. Deflection to the left before entry and exit.

III. Kerbs at the truck apron are high and sharp-edged.

IV. Traffic signs indicating roundabout are too near of the intersection or there is no information at all.

V. Winter maintenance is not satisfactory.

There still are opinions especially among the drivers of heavy vehicles, which are strongly against modern roundabouts. The aim of this study is to clarify and find out more detailed.

I. Whether the dimensions are according to the design guidelines or not.

II. Whether the speeds in the roundabout are too low.

III. Whether the dimensions are satisfied for heavy vehicle.

IV. Does the roundabouts work as planned.

2 GEOMETRIC DESIGN OF ROUNDABOUTS

2.1 Elements of roundabouts

The performance of roundabouts is related to a series of design, operational, and human factors. There are a lot of individual elements in modern roundabout design, some of which are interrelated. Considering 'heavy vehicles' in the roundabout, is one of the most important factors. The layout must provide a turning path for the largest design vehicle at the intersection. Other special vehicles should be considered to ensure satisfactory operation. In the roundabout design, there must be a suitable restricted design speed for all types of vehicles.

In designing a roundabout we have to consider a number of individual design elements to make it more appropriate. The basic elements are shown in *Figure 1.*

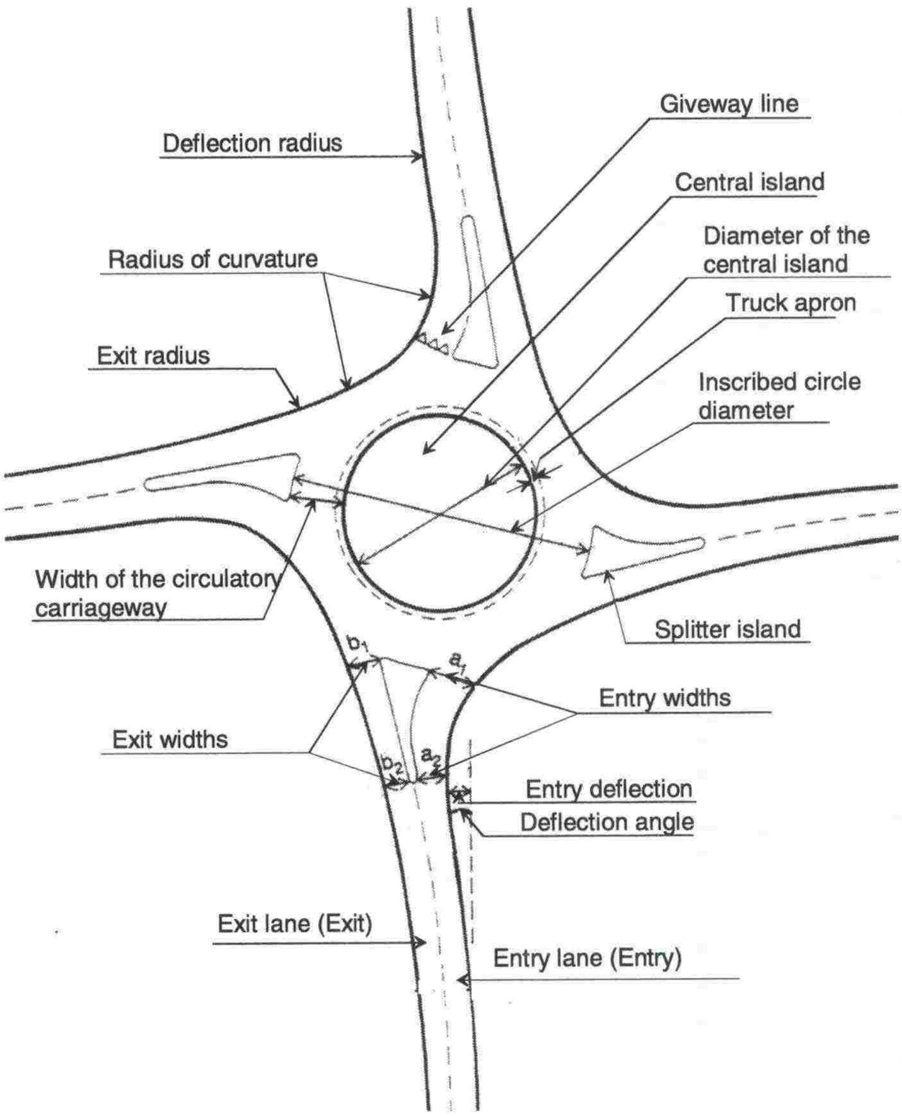


Figure 1: The basic design elements of a roundabout /2/.

Central island: Central island is a circular island in the middle of the roundabout and designed for not to drive-over. The radius varies according to the design parameters. The visibility of central-island is one of the significant factors in roundabout design.

Truck apron: Truck apron provides an extra space for heavy vehicles for passing through the roundabout safely. It also decreases speeds of passenger cars by preventing too straight vehicle path.

Entries and exits: The width of the entry roadway is one of the most important factors in designing roundabout. The entry width depends on design vehicles and their speed. When the approaching speed is high, it is better to reduce traffic speed gradually by introducing a horizontal reverse curve. Reversed curves are not suitable, when they cause obstructions or reduce visibility of the central island. A larger radius of exit lane will provide easier acceleration.

Circulatory roadway: On the roadway around the central island where vehicles travel counter-clockwise direction. The width of the circulatory roadway depends on the width of design vehicles that needs for its manoeuvres. It must be uniform through the circle.

Splitter/separator island: Almost all roundabouts are constructed with raised splitter island. These are commonly provided on the approach section for:

I. To allow drivers perceive the up-coming roundabout and reduce their speed.

II. Separate the entering and exiting traffic.

III. Create a place for mounting traffic signs.

IV. Provide a safe area for pedestrians and cyclist, also create a facility to cross the road in two stages.

Inscribed circle diameter: The circle, which inscribed within the outer curb line of the circulatory roadway. The inscribed circle diameter depends on the diameter of the central island and width of the circulatory carriageway.

Yield line: A line marked across the entry where entering vehicles wait for the gap if necessary.

Deflection: In designing modern roundabout the most important feature is to provide entry, through, the exit deflection /9/.

Staggering at the entry: The roundabout's entries ensure safety and adequate capacity /18/. It should be designed so that there is not possible to drive at high speed. Therefore the staggering is arranged at the entry lane, which will develop the perception of the junction and at the same time slow down the speed of vehicles /2/.

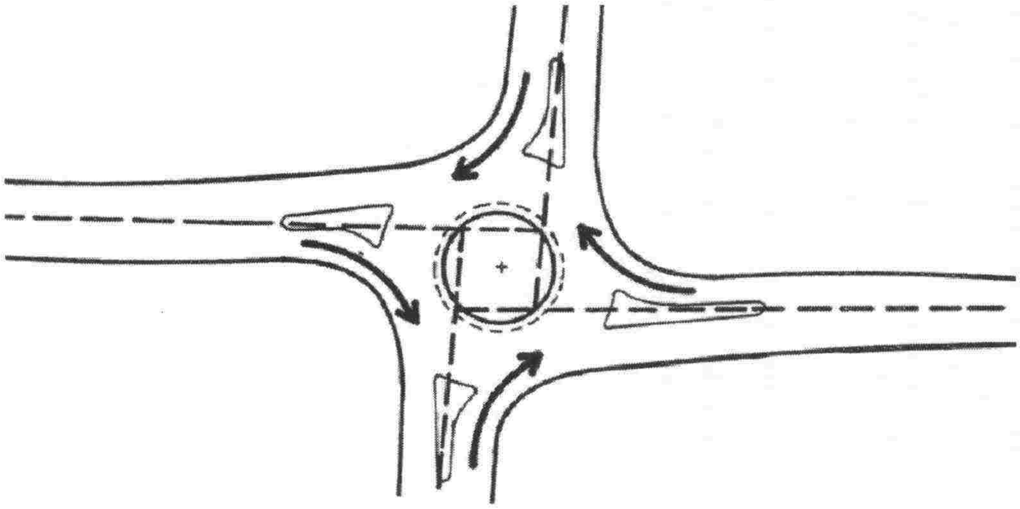


Figure 2: The staggering of a roundabout.

Signing and lighting: Mounting the information signs at all entries tell to the drivers about the up-coming change in geometry. Road lighting is one of the most important factors for the visibility.

Landscaping: The proper landscaping is the beauty of the roadside. Central-island can be used properly for landscaping to improve the freshness of the environment and also tell drivers about the undriveable zone of the intersection.

Bicycle and pedestrian consideration: In designing roundabout it should be kept in mind about the proportion of cyclist and pedestrian to provide a satisfactory level of safety.

Sight distance and visibility: Capability to see ahead is one of the most important factors in road design. Sight distance can be defined as the length of roadway ahead visible to the driver. The minimum length should be sufficient to enable a vehicle stop before reaching an object in its path. In the roundabout design left side visibility of the circulatory roadway as well as the visibility of left side approach are important. According to the UK design features, roundabout with the inscribed circle diameter less than 40.0 meters should provide the visibility of whole junction.

2.2 Geometry

The geometric design of roundabouts is related directly to the traffic operation and safety. The principal object of roundabout design is to secure the safe interchange of traffic between crossing traffic streams with minimum delay. As described before roundabout is to be designed by considering a number of individual elements some of which are interrelated. The capability of roundabout as an intersection is depending upon these design elements.

Now-a-days many European and other countries are influenced in designing modern roundabout by means of their advantages compared to the traditional intersection. Mostly they have their own geometrical measurements. The geometry is mainly depending upon the design vehicles and their speed. Thus they are different from each other according to their vehicle types. To design the most proper roundabout, the other important factors are circulatory carriageway, entry- and exit lanes, central island, and truck apron. An important determinant is vehicle deflection at entry, which adjusts the speed of a vehicle through the junction /20/. According to Bared et al. the single most significant feature of the modern roundabout design is to provide entry, through, the exit deflection. Each deflection should be developed with an individual radius not exceeding 100 metres /9/.

2.3 Design parameters

2.3.1 Design vehicles

According to the Finnish guidelines there is taken into account the turning path for the largest design vehicle. In the situation after the year 1997, when the module combination vehicles approved in Finland, the largest design vehicles become larger than that of before 1997. The maximum length of the module combination vehicle is 25.25 metres. This module combination needs 0.5-1.0 metres more turning space than 22.0 meter long truck and trailer. For this reason Finnra has already refined the guidelines according to module vehicles /14/.

For example the minimum turning path for different heavy vehicles can be calculated by the following methods (*Figures 3, 4 and 5*) /17/. In the calculation, rounding of the cab's corner and the steering centre of the axle group has been taken into consideration. The rounding of the cab's corner has showed in Appendix 1. The steering centre is assumed to be the centre of the gravity of the non-steering axles in the rear axle group.

Bus with bogie as a design vehicle (14.5 metres long):

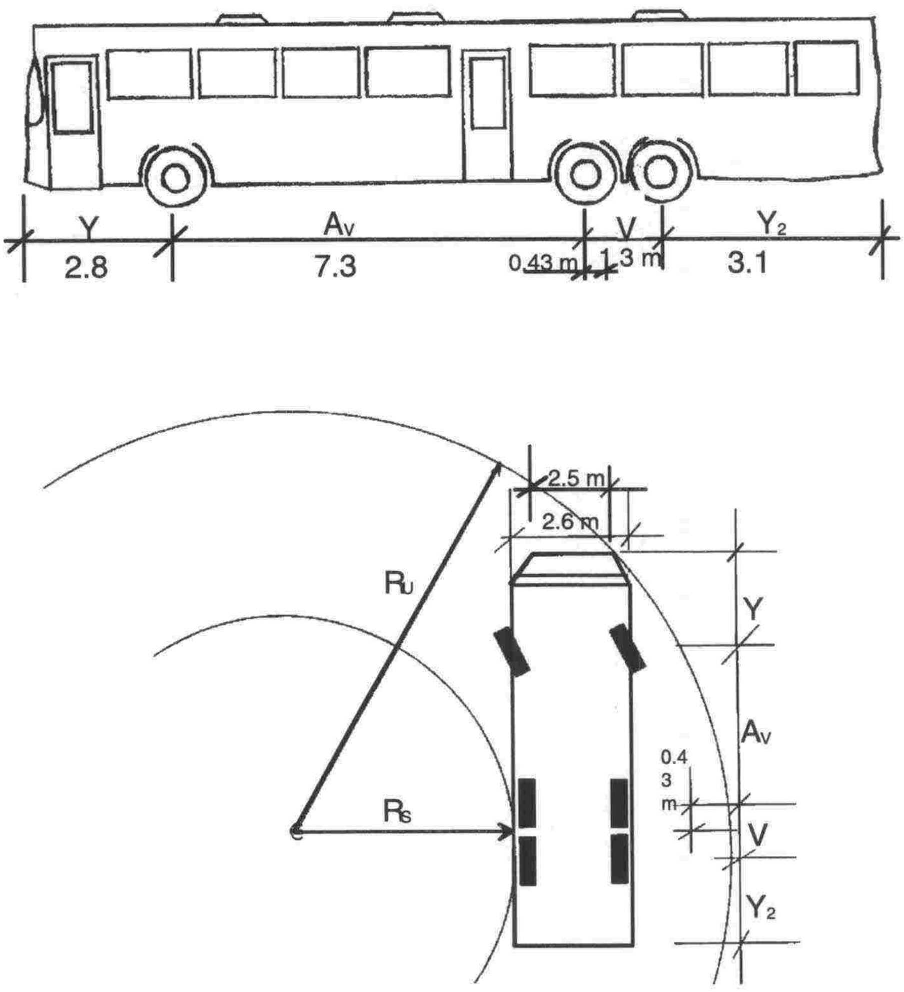


Figure 3: Minimum turning width of a bus with bogie.

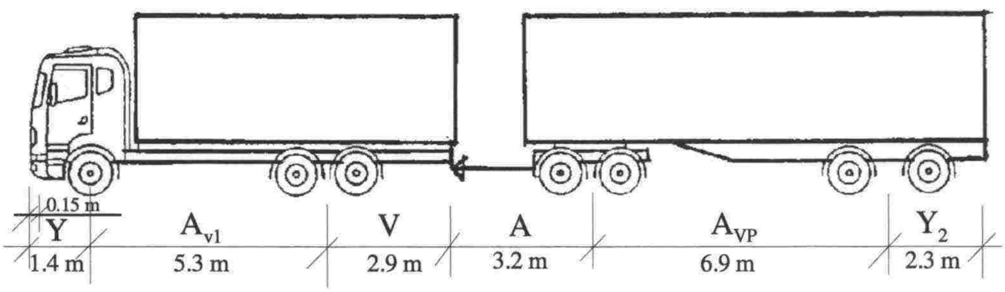
Radius of the inscribed circle, $R_U = 15.0$ m

Radius of the central island, $R_S = (R_U^2 - (Y + A_V + 0.43\text{ m})^2)^{1/2} - 2.55$ m.

=> $R_S = 8.1$ m

Width of the turning path = $(R_U - R_S) = 6.9$ m.

Truck and trailer as a design vehicle (22 metres long):



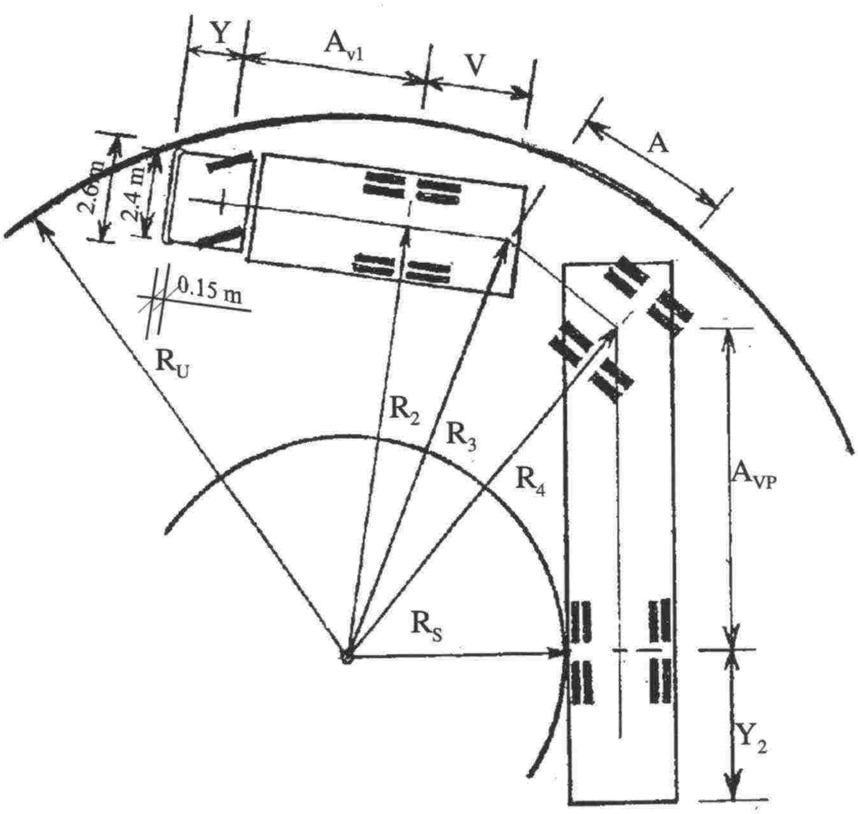


Figure 4: Minimum turning width of a truck and trailer.

Radius of the inscribed circle, $R_U = 12.5$ m

$R_2 = (R_U^2 - ((Y - 0.15\text{ m}) + A_{V1})^2)^{1/2} - 1.2\text{ m.} = 9.45\text{ m.}$

$R_3^2 = R_2^2 + V^2 = 97.71\text{ m}^2$

$R_4^2 = R_3^2 - A^2 = 87.47\text{ m}^2$

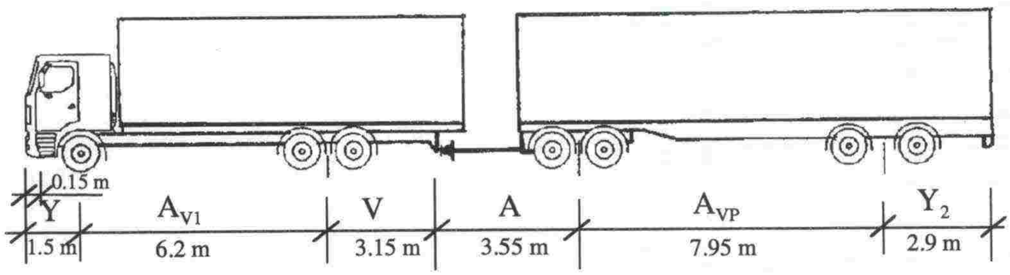
Radius of the central island, $R_S = (R_4^2 - A_{VP}^2)^{1/2} - 1.3\text{ m.}$

=> $R_S = 5.0$ m.

Width of the turning path = ($R_U - R_S$) = 7.5 m.

The width of the turning path will be 7.6 metres, if we don't consider the effect of the cab's taking-in and axle groups centre of gravity.

<u>Module combination as a design vehicle (25.25 metres long):</u>



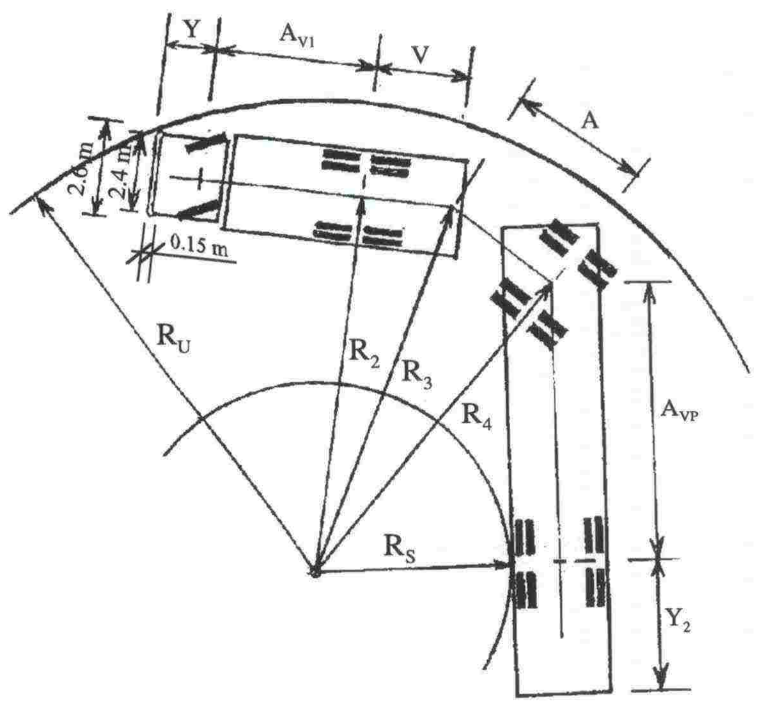


Figure 5: Minimum turning width of a module combination.

Radius of the inscribed circle, R_U = 12.5 m

$R_2 = (R_U^2 - ((Y - 0.15\ \text{m}) + A_{V1})^2)^{1/2} - 1.2\ \text{m.} = 8.76\ \text{m.}$

$R_3^2 = R_2^2 + V^2 = 86.7\ \text{m}^2$

$R_4^2 = R_3^2 - A^2 = 74.1\ \text{m}^2$

Radius of the central island, $R_S = (R_4^2 - A_{VP}^2)^{1/2} - 1.3$ m

=> $R_S = 2.0$ m.

Width of the turning path = $(R_U - R_S) = 10.5$ m.

The width of the turning path will be 11.6 meters, if we don't consider the effect of the cab's taking-in and axle groups centre of gravity.

2.3.2 Design speed

Roundabouts are designed so that the speed at the roundabout will be reduced to 20-40 km/hour. Maximum speed limit at the roundabout is 50 km/h. The decrease of speeds can be arranged about 150 meters before the intersection /2/.

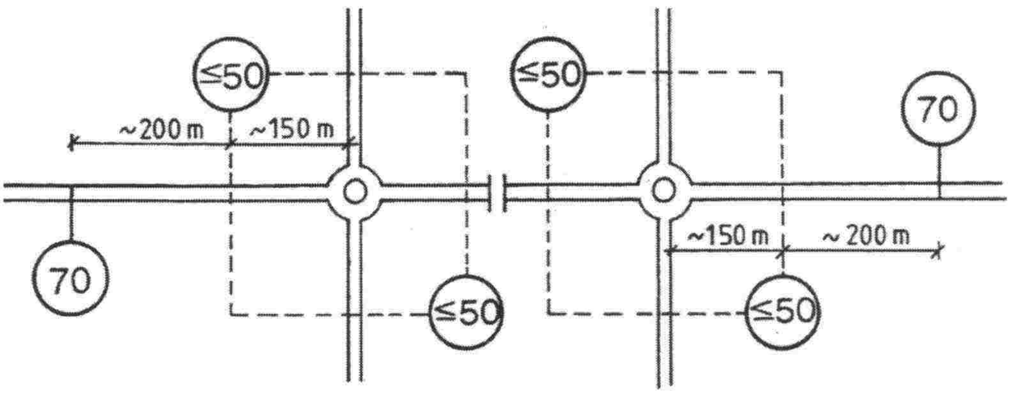


Figure 6: Speed limits arrangements at the roundabout.

The form of a roundabout should be designed so that passing through the intersection can not be possible without reducing the speed. The maximum radius of vehicle path (2.0 m wide) should be 70 metres and the maximum radius of the path of right turn should be 30 metres as shown in the *Figure 7* /2/.

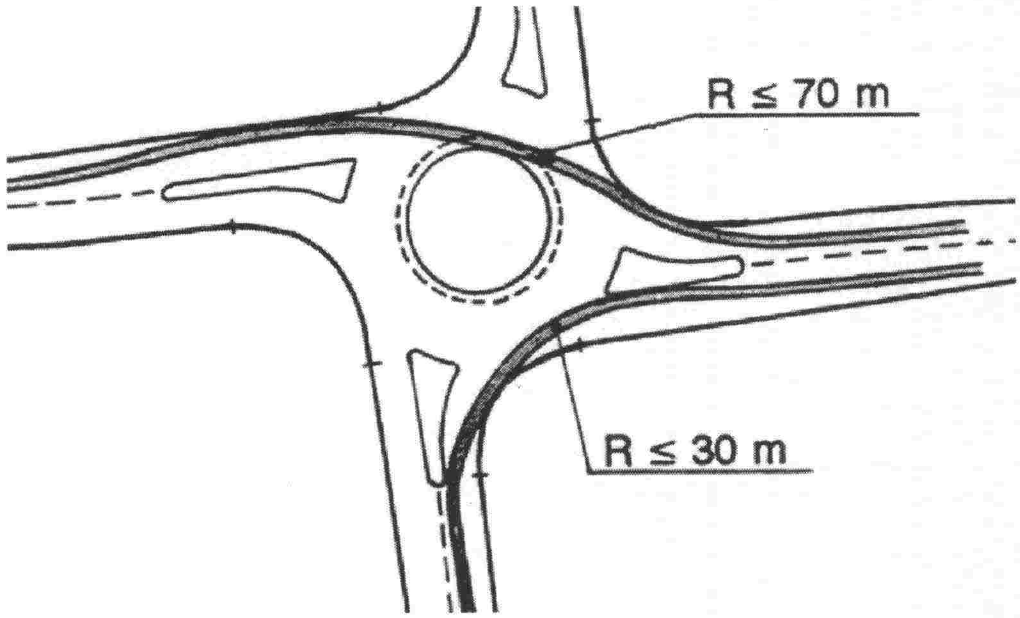


Figure 7: Values of the smallest possible curvature of the vehicle path.

2.3.3 Circulatory carriageway

The circulatory carriageway should be circular. The widths of the circulatory carriageway are shown in *Table 1*.

Table 1: The widths of the circulatory carriageways.

Type	Diameter of the central island (m)	Width of the circulatory carriageway (m)		
		Single lane	Double lane	
			Without road mark	With road mark
Mini	< 4	10.0 (9.0)		
Small	4 - 8	10.0 (9.0)		
	9 - 12	10.0 (9.0)		
Normal	13 - 15	9.0 (8.5)		
	16 - 20	8.5 (8.0)	12.0	
	21 - 25	8.0 (7.5)	11.0	
	26 - 30	7.5 (7.0)	10.5	12.0
	31 - 40	7.0 (6.5)	10.0	11.5
Big	41 - 50	6.5 (6.0)	*10.5/9.5 (8.5)	
	51 -60	6.0 (5.5)	*10.0/8.5 (8.0)	

Note: The values inside brackets were valid before the approval of module combination in the Finnish roadway.
**** The first parameter is valid in the year 1999 and the second one was. 1996-1999.***

2.3.4 Entry and exit lanes

The entry lane should be designed so that the drivers must slow down their speed. Therefore the entry lanes are usually deflected a little bit left before the entry to the roundabout according to the *Figure 8*. This should not exceed 3.5 metres. But if there is lower speed limit, for example in the built-up areas, the deflection may be less than 3.5 metres or no deflection at-all. The widths in different conditions are shown in *Table 2* /2/.

The exit lane should be designed so that the drivers are able to leave the roundabout flexibly. If there is a pedestrian or bicycle crossing on the exit lane, the speeds of vehicles should be reduced by designing smaller radius. The geometric design principles are presented in *Figure 8* and *Table 2* /2/.

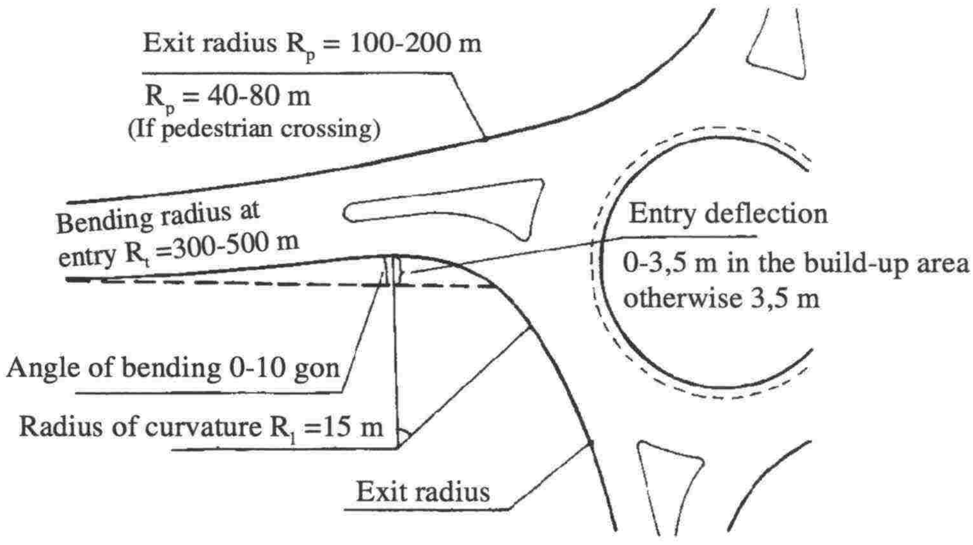


Figure 8: Entry deflection and curve radius at the exit of a roundabout.

Table 2: Entry and exit widths of the roundabout.

	Single lane				Double lane	
	Collecting roads		Major roads		Collecting roads	
Entry widths (m)	a_2 4.0 (4.0)	a_1 6.0 (5.5)	a_2 4.5 (4.5)	a_1 6.5 (6.0)	a_2 7.5 (7.5)	a_1 10.0 (9.5)
Exit Widths (m)	b_1 5.0 (5.0)	b_2 4.0 (4.0)	b_1 5.5 (5.5)	b_2 4.5 (4.5)	b_1 7.5 (7.5)	b_2 7.5 (7.5)

Note: The values inside brackets were designed before the approval of module combination in the Finnish roadway.

2.3.5 Central island and truck apron

The central island is a circular island and it is not planned to drive-over. The visibility of central-island is a significant factor in roundabout design. The diameter varies according to the design parameters. These are shown in the *Table 1* for different types of roundabouts.

There are an area called truck apron between the circulatory carriageway and the central-island to allowing more space for long vehicles. It should be designed so that it forces also passenger car's drivers to decrease their speed at the roundabout. The materials of the apron may be road-bricks, stones or any other rough surfaced road materials. It should not build by sharp-edged materials. The slope is the same as the slope of the circulatory carriageway (<2.5%). The widths are present in the *Table 3* /2/.

Table 3: The widths of the truck-apron for different types of single lane roundabouts.

Type	**Widths of the truck apron (m)**
Mini	-
Small	≤ 2.5
Normal	≤ 2.0 (D = 13-25 m)* ≤ 1.5 (D = 26-40 m)*
Large	≤ 1.0

**** D = Diameter of the central island.***

2.4 The use of roundabouts

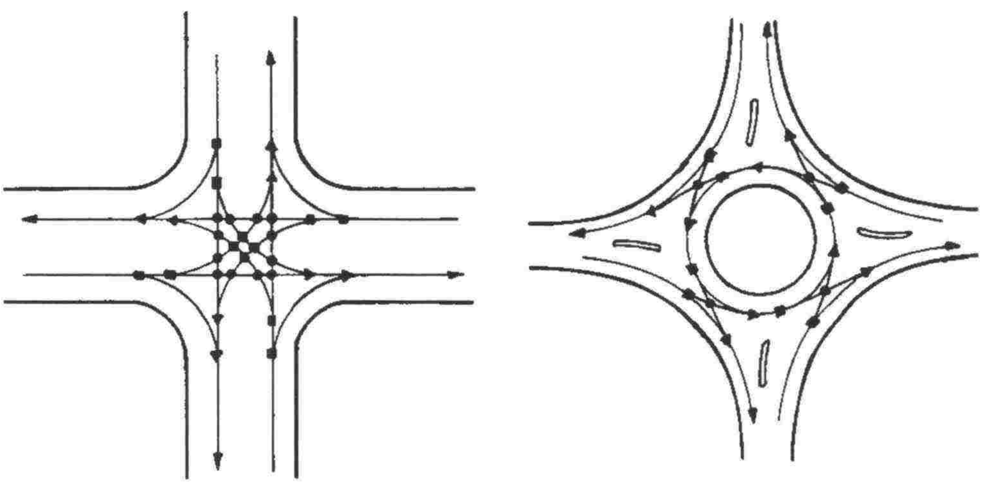
2.4.1 Roundabouts in Finland

Most of the old traffic circles were built in Finland in the mid 50's. Because of many negative results those were changed to normal at-grade intersection in 1970-1980. Problems caused mainly the driving priority rule used. Also geometry of roundabouts allowed high vehicle speeds and thereby problems with traffic safety.

Finnra started think about the roundabout again as a safer junction type at the end 1980's and the first new type roundabout was built in 1990 at Lammi. The research work proved that the safety increased six times and the traffic capacity increased 30-40% /4/.

Roundabouts have fewer conflict points than ordinary four-way junctions. Roundabouts force drivers to slow down, especially when they are entering built-up areas and they improve the visual appearance of the approach to the built-up area. Moreover, the absence of traffic lights means that there are no unnecessary delays during quiet periods. Accidents at roundabouts are also fewer in number and less serious compared with those at four-way junctions, for example.

Figure 9: The conflict points between roundabout and 4-legs intersection in different traffic stream.



● = *16*	● = *Intersecting traffic stream*	● = *4*
■ = *8*	■ = *Diverging traffic stream*	■ = *8*
▲ = *8*	▲ = *Merging traffic stream*	▲ = *8*

Roundabouts are classified into four different categories according to their size. These are mini, small, normal and large. The classification is based on the diameter of the central island, which fluctuate between less than 4 metres to greater than 40 meres. The types are presented in details in the *Table 4* /2/.

Table 4: Types of single lane roundabouts and their usage.

Diameter of the central island	**< 4 m**	**4 – 12 m**	**13 – 40 m**	**> 40 m**
Type	Mini	Small	Normal	Large
Location	Local street	Urban area	Sub-urban area	Rural area
Speed limit (km/h)	≤ 40 (50)	≤ 50 (60)	40-70	≤ 70 (80)
Traffic volume at the intersection. (vehicle/h)	< 1000	1000-2000	2000-3000	3000-3500

2.4.2 Roundabouts in Sweden

Sweden has been one of the leading European country in terms of road safety /12/. Swedish has a tradition of using roundabouts in the traffic planning from the year 1950 /6/. Some factors why Swedish interested in roundabouts are listed below /3/:

I. The safest type of junction.

II. The capacity is higher and waiting time is lower.

III. Fluent traffic flow, which reduce environmental impact of noise and dust.

IV. Low maintenance cost compared to traffic signals.

From a ‘before and after’ study they have found that the accident risk reduction for all road users is about 35 %. The most common accident type is single accidents.

Swedish have found that two roundabouts can be placed close to each other without any negative effect on the capacity. Intersections between two roundabouts can be simplified by removing the possibilities of left turning. The arrangements can be explained as following /3/.

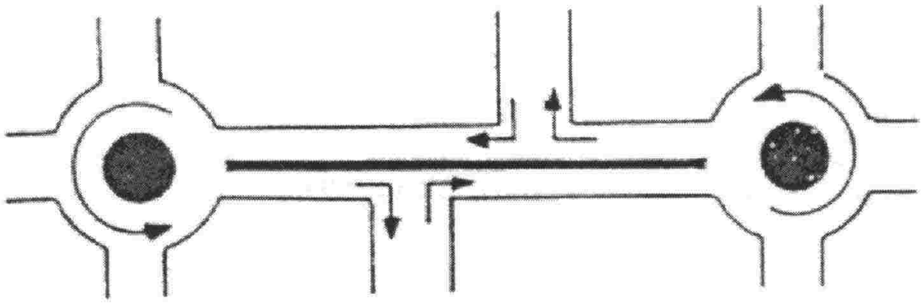


Figure 10: Removing the possibilities of left turn at the intersections between two roundabouts.

In the same research they reported disadvantages of the roundabout too. These are as follows /3/:

I. No possibilities to give priority for public transportation.

II. It is difficult to design a suitable roundabout with a large number of heavy vehicle and cyclist.

III. Snow clearance in a small roundabout is difficult.

IV. The steep gradient over 4% may cause heavy vehicles overturning.

The recommended diameter for public roads is 20 - 40 metres. The geometry of the entry should be designed so that, speed at the intersection will be low. At the exit lane the radius of curvature is between 100-200 metres. To control speed as well as safety, radius of curvature is the main important factor in designing a roundabout. When radius of curvature is under 100 m, this prevents that drivers of passenger cars are not able to make a shortcut through the roundabout. By practice 100 metres radius allow driving at the rate of 50 km/h.

3 STUDIED ROUNDABOUTS AND RESEARCH METHOD

3.1 Selecting roundabouts and studied roundabouts

Modern roundabouts have become a subject of great interest over the last few years. The Finnish National Road Administration has already built over 120 roundabouts in the 1990's. In this study, a total of ten roundabouts in different parts of Finland were chosen, eight of them are located on the main road network (*Appendix 2*). The final selections of the roundabouts were performed in terms of all the following conditions:

I. Modern roundabouts on the main roads.

II. Enough number of heavy vehicles (also buses).

III. Roundabouts with a-lot-of criticise of road users.

IV. Different diameter of the central island.

The selected roundabouts were studied both in winter and summer circumstances. The study of the roundabouts included vehicle speeds, vehicle paths and geometric parameters. The environmental factors on the each observed days at the chosen roundabouts are described below.

Muhos

During the observation period the driving behaviour does not affected by the road surface both in summer and winter. Though the road surface was wet in winter, it does not cause any influence in driving characteristics and there was also enough light for sight distances. Melted snow caused a wet surface, but water passed away gently from the carriageway. So there was no accumulated water on the roundabout, which may cause danger. It was accumulated snow on the side of the entrance and exit lanes, which made the widths of the above lanes a little bit smaller.

Kaustinen

In the winter, environment causes a little affection in the driving behaviour because of gentle raining. The road surface was wet from melted snow and drops of rain. But the surface water passed away from the carriageway gently. There was no accumulated water on the roadway and also the visibility was not so poor, that it would have created dangerous situations.

Virrat

The winter observed day was rainy and foggy, but about after 11:00 AM the sky was clear enough for collecting data and at the same time the rain has stopped. The road surface was wet from melted snow and rainwater. But because the surface water passed away from the carriageway gently, there was no accumulated water on the roadway that may have caused danger. Also the visibility was not so poor. In summer the observed day was cloudy, but there was sufficient light for sight distances. The road surface was dry.

Keuruu

During the observation period driving behaviour was not affected by the road surface both in summer and winter, but perhaps the weather caused a little affection in winter because of a gentle raining. The road surface was wet for melted snow and rainwater, but the surface water passed away from the carriageway. There was no accumulated water on the roadway.

Kangasala

At Kangasala there were two sites, one was at Valkeakoskentie and another was at Alasentie. On the both observed days in winter, the road surface was slippery because of hardened snow, which perhaps affected to the normal driving behaviour. For improving the service level at Valkeakoskentie the road surface was first plowed and then treated with salt and sand. But still for the slipperiness there were trouble at the circulatory carriageway, where the rear wheels skidded to the outer direction. In case of Alasentie, there was snowing all the time and no maintenance work had been done. For these circumstances, the conditions were weaker than that of Valkeakoskentie. On the both sites accumulated snow covered the truck apron, which was icy and made the vehicles skid outwards. Also it was very difficult to the drivers to locate the kerb of the central island. *Figure 11* shows the circumstances in winter at the roundabout of Alasentie. In summer no environmental effects were observed in both intersections.

Figure 11: The winter circumstances at the roundabout of Alasentie (Kangasala).

Hämeenlinna

In winter the road surface was slippery for hardened snow and also there was snowing all the observed time, which affect the normal driving behaviour. To increase the service level the road surface was plowed then treated with salt and sand. But still for the slipperiness there were troubles at the circulatory carriageway, where the rear wheels skidded to outer direction. Accumulated snow covered the corner stones and the worst part was that area, which covers the distance of 0.5 meter from the outer direction of the central island's kerb. There found no difficulties at the entrance or exit lane, though it seems that accumulated snow made narrower the width of exit lane.

Hämeenkyrö

There were chosen two roundabouts at Hämeenkyrö. One of them is located at the road number 3 and Härkikuja junction (Hämeenkyrö-1, Härkikuja) and another at the road number 3, 249 and 3002 junction (Hämeenkyrö-2, Esso). In summer both observed days were shiny and road surface was dry. In winter there were also shiny but the road surface was icy. At Hämeenkyrö-1 the maintenance work was not satisfactory. Accumulated snow by the side of entrance and exit lane made them narrower. Also the truck apron was covered by hardened snow, which forced vehicles' rear wheels to skid towards outer direction.

At Hämeenkyrö-2, there was snowing gently and the road surface covered by snow. Maintenance work has been done at about 11:00 and 12:30 PM. But still the worst part of the roundabout was the truck apron. *Figure 12* shows the winter circumstances at the roundabout of Hämeenkyrö-2.

Figure 12: The winter circumstances at the roundabout of Hämeenkyrö-2 (Esso).

Jämsä

The road surface was slippery for hardened snow and also there was snowing gently all the time when the observation was performed in winter. To increase the service level the road surface was treated with salt and sand. But still for the slipperiness, there were troubles at the circulatory carriageway, where the rear wheels skidded towards the outer direction. Accumulated snow covered the central island's kerb and the truck-apron. The worst part was the area, which covered the distance of 0.5 meter from the kerb to the outer direction of the central island. Also the drivers had difficulties to detect the kerb of the central island. No environmental effect observed in summer though the day was lightly cloudy. The winter circumstance at Jämsä is shown in the *Figure 13*.

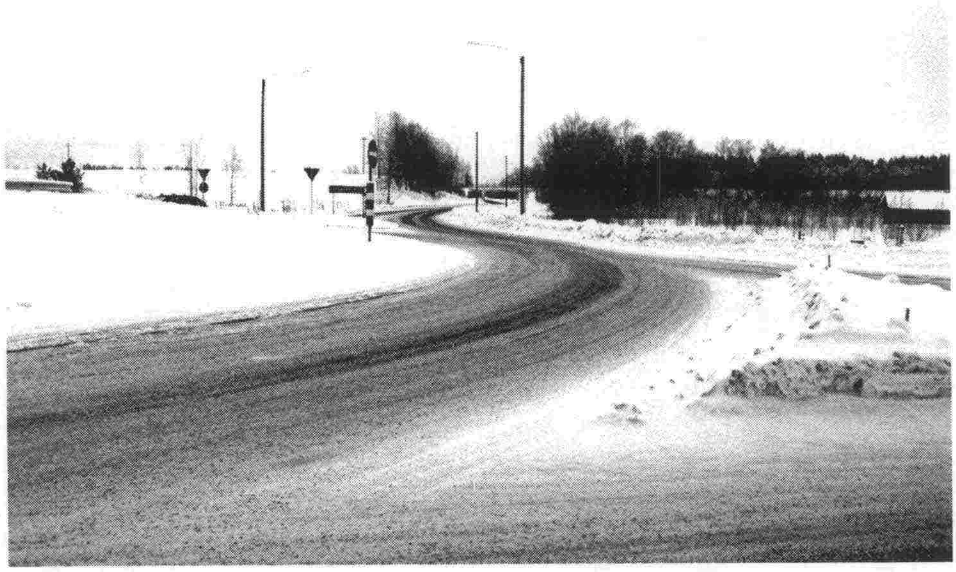


Figure 13: The winter circumstances at the roundabout of Jämsä.

The summaries of the observed environmental factors on chosen roundabouts are shown in the *Table 5*.

Table 5: Summary of the observed environmental factors on the chosen roundabouts.

Location	Date	Day condition	Road surface	Temperature	Visibility
Road no. 22 Ponkilantie, Muhos	02.12.1998	Lightly cloudy	Wet	+8.0°C	Good
	28.04.1999	Shiny	Dry	+11.0°C	Good
Road no. 13/63 Kaustinen	19.01.1999	Rainy	Wet	+1.5°C	Satisfactory
	09.06.1999	Shiny	Dry	+20.0°C	Good
Road no. 66/14362 Virrat	20.01.1999	Lightly cloudy	Wet	+2.0°C	Good
	04.06.1999	Lightly cloudy	Dry	+12.0°C	Good
Road no. 23/16511 Keuruu	21.01.1999	Rainy	Wet	+1.5°C	Satisfactory
	07.05.1999	Shiny	Dry	+4.0°C	Good
Road no. 339/310 Valkeakoskentie, Kangasala	02.02.1999	Lightly cloudy	Icy	-12.0°C	Good
	06.05.1999	Shiny	Dry	+11.0°C	Good
Road no. 339 Alasentie,Kangasala	03.02.1999	Snowfall	Icy	-7.5°C	Good
	05.05.1999	Gentle raining	Wet	+7.0°C	Satisfactory
Road no. 10/3053 Katinen,Hämeenlinna	04.02.1999	Snowfall	Icy	-2.0°C	Good
	04.05.1999	Cloudy	Dry	+7.0°C	Satisfactory
Road no. 3/249/3002 (Esso) Hämeenkyrö-2	10.02.1999	Shiny	Icy	-21.0°C	Good
	03.06.1999	Bright sun shines	Dry	+19.0°C	Very good
Road no. 3 Härkikuja, Hämeenkyrö-1	11.02.1999	Shiny	Icy	-18.0°C	Good
	02.06.1999	Bright sun shines	Dry	+12.0°C	Very good
Road no. 9/24 Jämsä	12.02.1999	Lightly cloudy (snowfall)	Icy	-14.5°C	Satisfactory
	03.05.1999	Cloudy	Dry	+5.0°C	Satisfactory

3.2 Data recording

In the very beginning of the study the test recording was done at Muhos. The data was collected in several ways for analysis. The data collection procedure included geometrical measurements, vehicle speed and video recording and recording vehicle path. The passing times were recorded individually for each vehicle by help of a stopwatch, during the observation in summer. That helps to calculate average speed at the circulatory carriageway, where there were disturbances in radar recording for too much deviation between radar and observed vehicles and also for the disturbances of other vehicles. Data was collected from morning to evening avoiding all time factors such as peak-hours.

Vehicle speeds between entry and exit points were recorded at the interval of 0.3 seconds with radar, which was linked with a portable computer. At the same time a video recording was performed by a video camera, which was placed at a distance of about 40 metres away from the exit point. The approach speeds were measured by another radar at the distance of 50 metres ahead from the intersection's entry. At this point drivers have to begin concentrate more to the roundabout manoeuvres.

Measuring the following parts of a roundabout in the field carried out the geometrical measurements (see *Figure 14*). The values of R (vehicle path curvature) are calculated from the geometrical measurements. The R-values are calculated in case of Kaustinen, Alasentie and Jämsä by considering no truck apron for their structures. The parameters of chosen roundabouts are present in the *Table 6*.

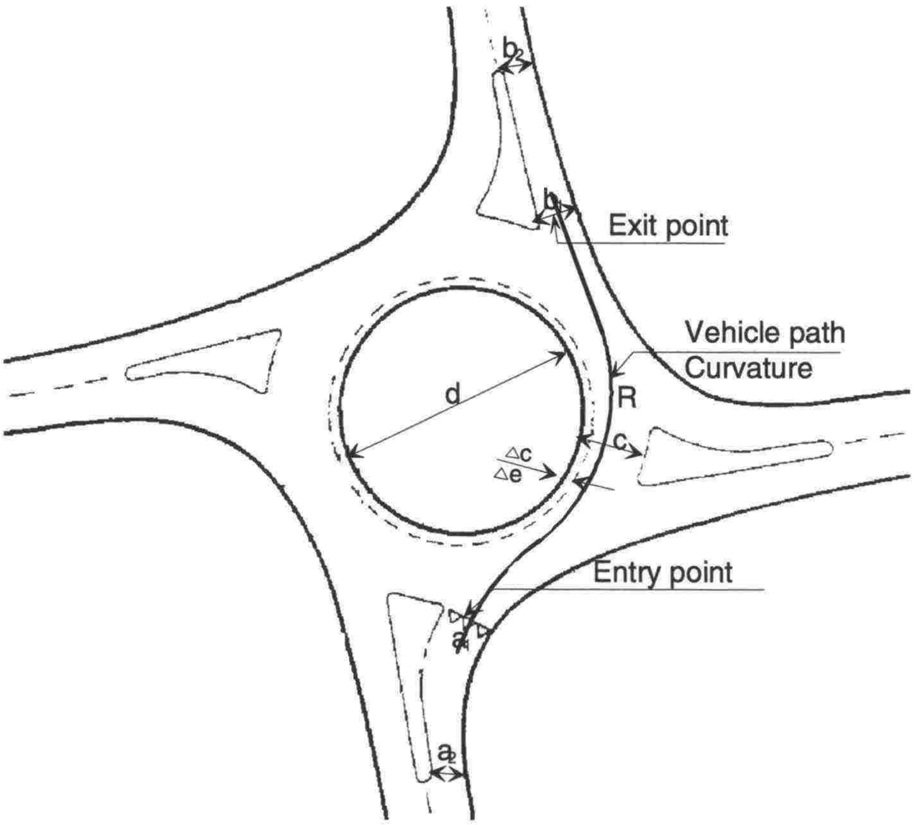


Figure 14: The geometrical parameters of a roundabout used in this study.

Table 6: Selected roundabouts and their dimensions in metres (see fig. 14 for the index of the used parameters).

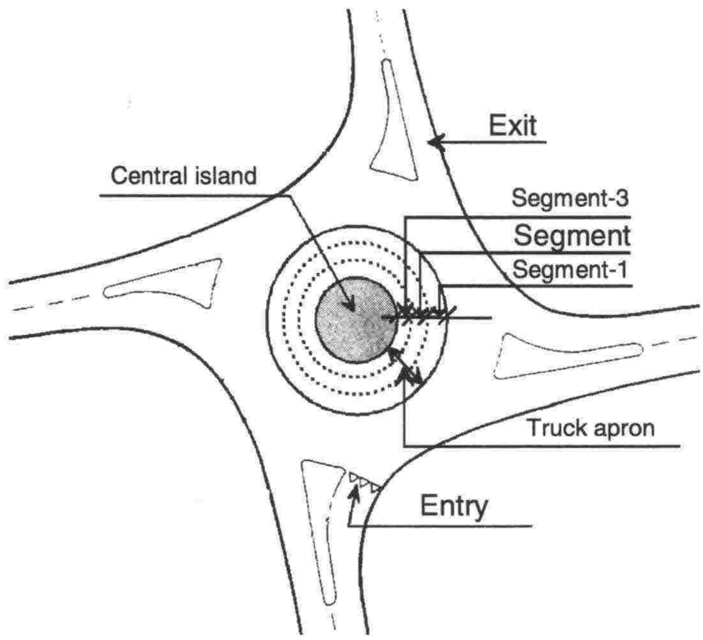
Location	a_1	a_2	b_1	b_2	c	Δ c	Δ e *	D	R
Road no. 22 Ponkilantie, Muhos	7.4	4.3	6.9	3.8	10.1	2.0	-	16	85
Road no. 13/ 63, Kaustinen	5.8	3.6	3.9	3.9	6.6 (7.6)	-	1.0	30 (28)	37 (43)
Road no. 66/ 14362, Virrat	7.1	4.5	6.4	5.2	6.5	1.0	-	35	29
Road no. 23/ 16511, Keuruu	7.5	5.5	4.7	4.6	9.7	2.5	-	20	50
Road no. 339/310 Valkeakoskentie Kangasala	5.9	4.3	5.2	3.9	7.0	1.0	-	30	50
Road no. 339 Alasentie, Kangasala	5.5	4.0	5.0	4.1	6.5 (8.0)	0.0	1.5	23 (20)	29 (37)
Road no. 10/ 3053, Katinen, Hämeenlinna	6.8	4.6	5.5	5.4	6.5 (9.0)	0.0	2.5	30 (25)	--
Road no. 3 Härkikuja, Hämeenkyrö-1	5.7	3.7	6.0	4.6	7.1	1.0	-	26	42
Road no. 3/249/ 3002 (Esso) (Hämeenkyrö-2)	7.4	4.3	6.5	4.2	6.2	1.0	-	40	31
Road no. 9/24 Jämsä	7.0	4.6	5.7	4.4	6.0 (7.0)	0.0	1.0	32 (30)	29 (33)

**** Note: The parameter Δ e represents the same parameter as Δ c. The cause of the separation Δ e from Δ c, is the structure of the truck apron. When there were high corner bricks at the truck apron structures, truck aprons were not considered as a part of the circulatory carriageway. But according to design there were truck aprons, which were not appropriately constructed. In these cases the truck aprons structures represented by Δ e and were not considered in this study as truck aprons. The values those are presented in the brackets would be the actual parameters, if there were no high kerbs at the truck apron.***

The vehicle path is recorded by marking segments at the rate of 0.5 metres from the kerb of the central island to the direction of the road surface. The system is explained below.

<u>System-1</u>

(When the vehicle path is straight through the roundabout)



<u>System-2</u>

(When the path turned to the left)

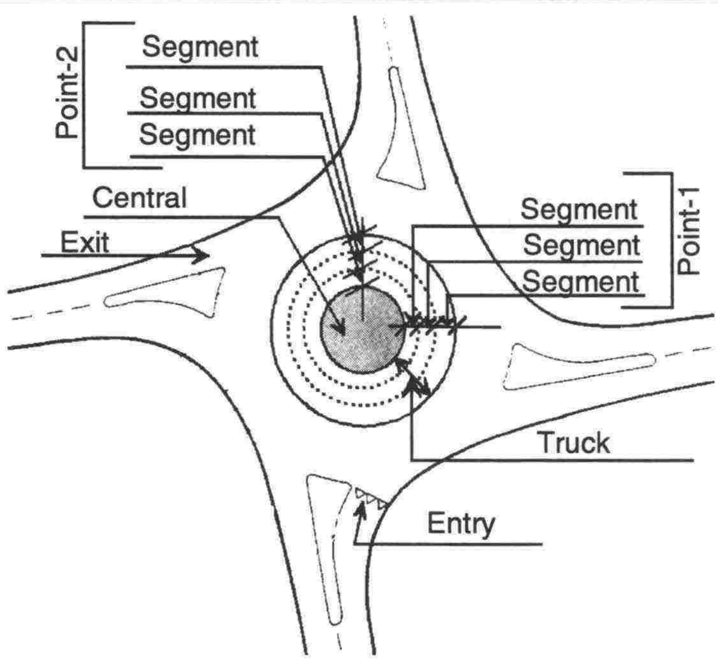


Figure 15: Vehicle path recording systems.

This study covers only the heavy vehicles, which are all types of buses, trucks and combination of truck and trailers. For the accuracy of the research work, observed vehicles are shared into Category 1 and Category 2. The vehicles belonging to these both categories are presented in the *Figure 16.*

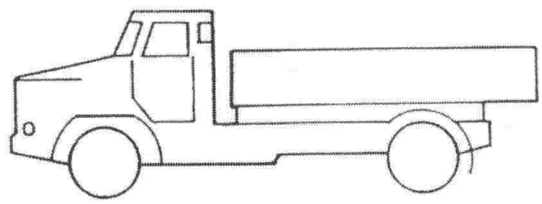
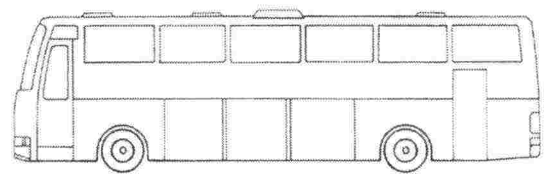
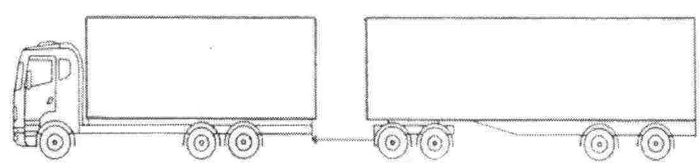
Category 1	 
Category 2	

Figure 16: Vehicle types as by category.

It is important to record the direction of observed vehicles for the comparing with geometry of the roundabouts. The direction at the each roundabout has been chosen in terms of the traffic flow. The directions of the vehicle paths at the each roundabout are presented in *Table 7.*

Location	Direction of the vehicle path	Path types
Muhos	Kajaani - Oulu	Straight
Kaustinen	Jyväskylä - Kokkola	Straight
Virrat	Orivesi - Lapua	Straight
Keuruu	Jyväskylä - Pori	Straight
Valkeakoskentie	Kangasala - Tampere	Straight
Alasentie	Kangasala - Tampere	Straight
Hämeenlinna	Lahti - Turku	Left turning
Hämeenkyrö-1	Tampere - Vaasa	Straight
Hämeenkyrö-2	Tampere - Vaasa	Straight
Jämsä	Tampere - Jyväskylä	Straight

Table 7: Directions of the selected vehicle paths on the chosen roundabouts.

4 ANALYSIS OF THE COLLECTED DATA

4.1 Data analysis procedure

The recorded data has been checked for accuracy in the very beginning of the analysis and some irrelevant recorded speeds were found out. In the following situations, speed profile data is not approved for the accuracy of this study:

I. Fragmented data from the vehicles, which had to stop at the entry.

II. Fragmented data from the vehicles when their speeds were less than 14 km/hour. The radar was not able to read speeds below 14 km/h.

III. Irrelevant speed profile data, which were caused by the disturbance of other vehicles.

IV. Fragmented speeds data caused from the reflections of other mistakes during observation.

Analysis procedure was performed into two steps; vehicle path analysis and vehicle speed analysis. For the vehicle speed analysis, recorded speeds were calibrated with video records where necessary. Speeds were calculated from the same path, passed by every vehicle. In the case of Kangasala (Valkeakoskentie and Alasentie) the vehicle type Category 1 represents only buses. Because a bus route lies through the intersections and also there are a lot of bus transportation than those of other observed intersections. The bus route was one reason to choose these roundabouts. The 12 - 14,5 metres long buses need more space when turning than ordinary trucks.

The collected data from Virrat, Hämeenkyrö-2 (Esso) and Hämeenlinna in winter was very poor for the speed analysis. In Virrat and Hämeenkyrö-2 a large amount of collected data was disturbed by influence of other vehicles. In Hämeenlinna it was found afterwards that there were too much deflection between the radar and observed vehicles for a relevant data. In summer the above problems were solved by modifying the data recording methods. The numbers of vehicles, which are used in speed analysis among the recorded vehicles, are shown in the *Tables 8* and *9*.

Table 8: The numbers of vehicles, which are used in speed analysis among the recorded vehicles for Category 1.

Location	Date	Recorded vehicles	Stopped at entrance	Speeds below 14 km/h	Irrelevant data	Unsufficient for cal.	Used in calculation
Muhos	02.12.98	7	-	-	-	-	7
	28.04.99	29	-	1	-	-	28
Kaustinen	19.01.99	6	-	1	-	-	5
	09.06.99	16	2	-	-	-	14
Virrat	20.01.99	15	1	-	10	4	-
	04.06.99	20	1	-	-	-	19
Keuruu	21.01.99	29	3	7	-	-	19
	07.05.99	35	3	2	-	-	30
Valkeakoskentie	02.02.99	27	-	-	-	-	27
	06.05.99	54	3	11	-	-	40
Alasentie	03.02.99	26	-	4	-	-	22
	05.05.99	44	5	14	-	-	25
Hämeenlinna	04.02.99	13	-	-	13	-	-
	04.05.99	22	2	-	-	-	20
Hämeenkyrö-1	11.02.99	28	-	2	-	-	26
	02.06.99	22	-	2	-	-	20
Hämeenkyrö-2	10.02.99	14	-	2	12	-	-
	03.06.99	27	-	8	-	-	19
Jämsä	12.02.99	17	6	7	4	-	-
	03.05.99	6	2	-		4	-
Grand total		**457**	**28**	**61**	**39**	**8**	**321**

Table 9: The numbers of vehicles, which are used in speed analysis among the recorded vehicles for Category 2.

Location	Date	Recorded vehicles	Stopped at entrance	Speeds below 14 km/h	Irrelevant data	Unsufficient for cal.	Used in calculation
Muhos	02.12.98	17	2	-	-	-	15
	28.04.99	32	-	3	-	-	29
Kaustinen	19.01.99	14	1	2	-	-	11
	09.06.99	15	2	-	-	-	13
Virrat	20.01.99	15	1	-	11	3	-
	04.06.99	26	4	2	-	-	20
Keuruu	21.01.99	12	2	1	-	-	9
	07.05.99	27	2	3	-	-	22
Hämeenlinna	04.02.99	25	4	-	21	-	-
	04.05.99	30	1	1	-	-	28
Hämeenkyrö-1	11.02.99	32	3	2	-	-	27
	02.06.99	42	-	7	-	-	35
Hämeenkyrö-2	10.02.99	26	5	8	13	-	-
	03.06.99	49	2	-	-	-	47
Jämsä	12.02.99	26	6	13	7	-	-
	03.05.99	36	5	6	-	-	25
Grand total		**424**	**40**	**48**	**52**	**3**	**281**

4.2 Vehicle path analysis

The vehicle paths of each vehicle were recorded in each intersection as described before. The calculation of the vehicle path curvature (R) has been done by considering no truck apron for their structures at the roundabout of Kaustinen, Alasentie and Jämsä. Also at the roundabout of Hämeenlinna there was high kerbs. But it is not included in the path analysis because of left turning traffic. The kerbs of the truck apron are 3-6 centimetres upper than the road surface and somewhere sharp. It was assumed that the drivers do not consider them over-riding and therefore the truck aprons were not included with the circulatory carriageway at all. It was observed that the drivers drove their vehicles as close as possible the truck apron. The *Figure 17* shows the circumstances at the Hämeenlinna roundabout when a bus drove through it. The whole straight path through the same roundabout is presented in the *Appendix 3.*

Figure 17: Truck apron structure at the roundabout of Hämeenlinna.

The vehicle paths differ remarkably in summer and winter circumstances and almost in every intersection for both vehicle categories. The paths were generally closer to the kerb of the central island in winter than that of in summer at the same intersection. The vehicle paths were closer to the central island in summer for Category 1 vehicles at the roundabouts of Virrat, Valkeakoskentie, Jämsä and Hämeenlinna. For Category 2 vehicles the vehicle paths were closer to the central island in summer at the roundabouts of Muhos, Virrat and Hämeenlinna. Based on the recorded data the vehicle paths looked to depend on the curvature of the vehicle path (R) and widths of the circulatory carriageway (c). The both factors affect in together the paths of the vehicles. But the effect of the width of the circulatory carriageway is more remarkable. Among the roundabouts of Keuruu and Valkeakoskentie, the path is nearer at the roundabout of Valkeakoskentie compared to Keuruu. The values of R are 50 metres in both intersections, but the width of the circulatory carriageway at Valkeakoskentie is smaller than that of Keuruu. The smaller path curvature and width of the circulatory carriageway would create the vehicle path nearer to the central island.

As described before the vehicle paths were depended on the geometrical parameters (size) of the studied roundabouts. These paths would be divided mainly into two groups. In the first group, drivers entered into the roundabout and at the same time turned to the right for passing through the roundabout. On the other hand in the second group, the drivers entered into the roundabout and drove straight near the central island and then turned to the right for passing through the roundabout. There were no difficulties found in both cases, but the second type had made the vehicle paths closer to the central island. *Figure 18* and *19* show those different types of entry at the roundabout of Hämeenkyrö-1 (Härkikuja) and Hämeenlinna. The summaries of the recorded vehicle paths are shown in the *Tables 10* and *11*.

Figure 18: The entry of a Category 2 vehicle into the roundabout of Hämeenkyrö-1 (Härkikuja).

Figure 19: The entry of a Category 2 vehicle into the roundabout of Hämeenlinna.

Table 10: Summary of the observed vehicle path for Category 1 vehicles.

Location/ Parameters	Date	No. of vehicles	Minimum distances of vehicles (in persentages) from the central island				
R, c (metres)			**0- * point**	**0-0.5 (m)**	**0.5-1.0 (m)**	**1.0-1.5 (m)**	**>1.5 (m)**
Muhos/ (85, 10.1)	02.12.98	8	-	-	75	12.5	12.5
	28.04.99	31	-	-	32.3	29.0	38.7
Kaustinen/ (37, 7.6)	19.01.99	6	-	-	-	33.3	67
	09.06.99	23	-	-	-	-	100
Virrat/ (29, 6.5)	20.01.99	16	-	25	50	25	
	04.06.99	27	-	7.4	66.7	24.9	
Keuruu/ (50, 9.7)	21.01.99	22	-	-	-	36.4	63.6
	07.05.99	44	-	-	11.4	18.2	70.4
Valkea-koskentie/ (50, 7.0)	02.02.99	33	-	45.4	33.3	21.3	
	06.05.99	64	26.6	53.1	17.2	3.1	
Alasentie/ (29, 6.5)	03.02.99	38	5.3	79	15.7		
	05.05.99	58	-	62.1	32.7	5.2	
Hämeen-linna/ (-, 6.5)**	04.02.99	15	-	26.7/13.3	33.3/13.3	40/73.4	
	04.05.99	28	-	46.4/7.11	10.7/17.9	42.9/75	
Hämeen-kyrö-2/ (31, 6.2)	10.02.99	14	-	64.3	28.6	7.1	
	03.06.99	29	-	-	31	48.3	20.7
Hämeen-kyrö-1/ (42, 7.1)	11.02.99	35	2.9	51.4	45.7		
	02.06.99	32	-	-	40.6	50	9.4
Jämsä/ (29, 6.0)	12.02.99	20	-	-	5	50	45
	03.05.99	19	-	-	-	57.9	42.1

** ***At the roundabout of Hämeenlinna, the data was collected from the left-turning traffic. The values presented in the table as, point-1 segment-2/point-2 segment-2 and point-1 segment-1/point-2 segment1. See Figure 15 for details.***

* ***'0' point is the kerb of the central island, but at the Hämeenlinna this point is the kerb of the circulatory carriageway.***

Table 11: Summary of the observed vehicle path for Category 2 vehicles.

Location/ Parameters	**Date**	**No. of vehicles**	**Minimum distances of vehicles (in persentages) from the central island**				
R, c (m)			**0-* point**	**0-0.5 (m)**	**0.5-1.0 (m)**	**1.0-1.5 (m)**	**>1.5 (m)**
Muhos/ (85, 10.1)	02.12.98	16	-	-	75	18.8	6.2
	28.04.99	33	-	6.1	42.4	33.3	18.2
Kausti-nen/ (37, 7.6)	19.01.99	17	-	-	-	70.5	29.5
	09.06.99	20	-	-	-	15	85
Virrat/ (29, 6.5)	20.01.99	15	-	86.7	13.3		
	04.06.99	31	16.1	45.2	25.8	15.9	
Keuruu/ (50, 9.7)	21.01.99	12	-	-	-	41.7	58.3
	07.05.99	33	-	-	3	24.2	72.8
Hämeen-linna/ (-, 6.5)**	04.02.99	23	-	43.5/21.7	17.4/8.7	38.7/69.6	
	04.05.99	34	2.9/-	41.2/17.6	32.4/8.8	26.4/73.6	
Hämeen-kyrö-2/ (31, 6.2)	10.02.99	26	-	53.8	19.2	27	
	03.06.99	57	-	3.5	38.6	54.4	3.5
Hämeen-kyrö-1/ (42, 7.1)	11.02.99	54	1.8	79.6	11.1	7.5	
	02.06.99	46	-	23.9	41.3	34.8	
Jämsä/ (29, 6.0)	12.02.99	29	-	-	3.4	80	16.6
	03.05.99	54	-	-	13	67.7	19.3

** ***At the roundabout of Hämeenlinna, the data was collected from the left-turning traffic. The values presented in the table as, point-1 segment-2/point-2 segment-2 and point-1 segment-1/point-2 segment1. See Figure 15 for details.***

* ***'0' point is the kerb of the central island, but at the Hämeenlinna this point is the kerb of the circulatory carriageway.***

4.3 Speed analysis

The recorded speeds were analysed by normal cumulative distribution. In some observed roundabouts there were insufficient data for the normal distribution. In these cases it was assumed that the recorded speeds were normally distributed and thus performed the calculations. Also the speed data and the other geometric design elements were statistically analysed (*Appendix 4*).

In all observed roundabouts, the vehicles had to reduce their speeds to the level of about 22 - 26 km/hour at the circulatory carriageway. In the roundabouts of Virrat, Hämeenkyrö-1 (Härkikuja) and Jämsä the average speeds decreased below 20 km/hour of Category 2 vehicles, which can be considered too low speed to pass a roundabout. *Figure 20* represents a model of speed distribution at the circulatory carriageway and 50 metres away from it at the roundabout of Muhos in winter.

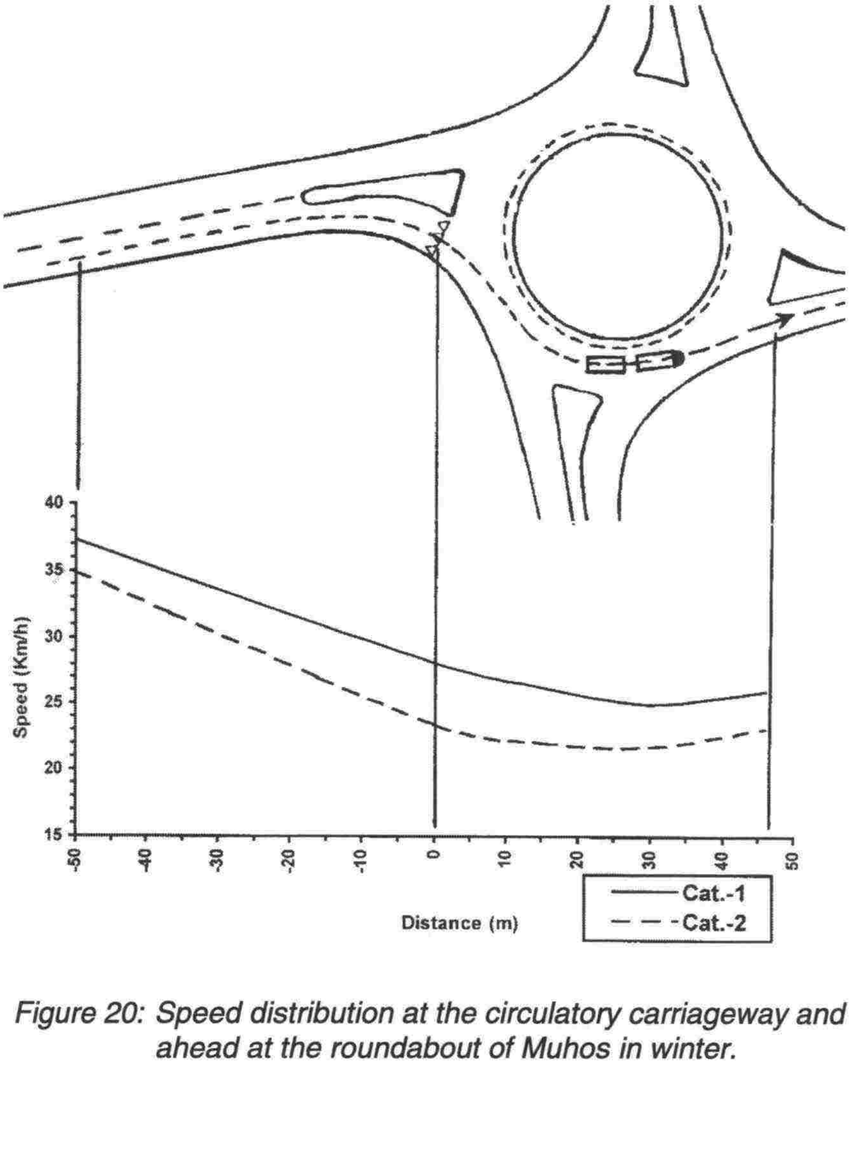


Figure 20: Speed distribution at the circulatory carriageway and 50 meters ahead at the roundabout of Muhos in winter.

The calculations of the correlation coefficients show that, the used speeds at the circulatory carriageway directly correlate with the width of the circulatory carriageway and the curvature of the vehicle path. The speeds will increase according to the increasing of both these two parameters. The influence of the width of the circulatory carriageway was stronger in winter than in summer for Category 1 vehicles. For Category 2 vehicles the width of the circulatory carriageway looked to influence stronger in summertime. The vehicle path curvature did not influenced as strongly into the speeds of the two vehicle categories in winter as in summer. The vehicle path curvature influenced to the increase of speeds more for Category 1 vehicles than for Category 2 vehicles in summer. The central island diameter (16 - 40 metres) had a negative influence in speeds, in both vehicle categories. When the diameter increases the speed decreases at the circulatory carriageway in both summer and wintertime for both types of vehicles. The correlation coefficients are presented in the *Table 12.*

Table 12: The correlation coefficients between the geometrical parameters and speeds (km/h) at the circulatory carriageway.

	Speeds in winter		*Speeds in summer*	
	Category-1	*Category-2*	*Category-1*	*Category-2*
R	0.6004	0.2688	0.8281	0.6149
c	0.9587	0.6104	0.8578	0.6974
D	-0.6916	-0.2317	-0.6017	-0.5126

** ***R = Vehicle path curvature***
c = Width of the circulatory carriageway
D = Central island diameter

The speed differences between entry, exit and at the circulatory carriageway were not remarkable at all observed roundabouts. The only exception was the roundabout of Jämsä, where the difference in the average speed between entry and circulatory carriageway was even 6.7 km/hour for Category 2 vehicles in summer. Though the correlation coefficients are not statistically so strong, *Table 13* shows that the reduction in speeds between circulatory carriageway and entry increased a little bit when the vehicle path curvatures are smaller.

Table 13: The correlation coefficients between the geometrical parameters and reductions in speeds (km/h) in-between entry and circulatory carriageway.

	Speed reductions in winter		*Speed reductions in summer*	
	Category-1	*Category-2*	*Category-1*	*Category-2*
Vehicle path curvature (R)	-0.0640	-0.4148	-0.1925	-0.4750

The path through the roundabout tends to straighten with the increasing of the path curvature. Thus speed continued almost at the same rate as the speed at the entry. According to the *Table 14* and *15* Category 2 vehicles looked to have more difficulties in the small path curvature than Category 1 vehicles.

Table 14: Summary of the analysed speeds both in winter and summer for the vehicles belongs to Category 1.

Location/ Vehicle path curvature, R (m)	Date	Mean speed st.deviation Entry	Exit	Speed at the carriageway Mean*	V_{85}	V_{max}
Muhos/ 85	02.12.98	29.1/4.3	27.0/3.7	26.0 (25.5)	30.0	31.3
	28.04.99	27.8/4.3	27.3/3.9	25.7 (25.1)	29.7	32
Kaustinen/	19.01.99	26.8/1.6	27.8/2.9	25.1 (24.9)	27.6	27.3
	09.06.99	26.6/5.4	24.6/1.7	22.2 (21.9)	25.2	26.8
Virrat/ 29	20.01.99	--	--	--	--	--
	04.06.99	21.7/3.0	--	21.3 (20.9)	24.1	25.5
Keuruu/ 50	21.01.99	29.6/3.7	27.1/4.4	26.2 (25.8)	29.9	37
	07.05.99	25.5/3.8	28.0/3.9	24.7 (24.3)	28.0	32
Valkeakosken tie/ 50	02.02.99	23.9/3.7	23.7/2.8	21.7 (21.6)	23.3	24.9
	06.05.99	21.7/3.6	24.0/2.6	20.8 (20.5)	23.4	29.4
Alasentie/	03.02.99	25.2/4.0	21.7/2.2	20.4 (20.2)	22.2	24.4
	05.05.99	24.7/4.0	23.9/3.3	21.0 (20.8)	23.2	26
Hämeenlinna/	04.02.99	23.7/5.1	26.4/3.6	--	--	--
	04.05.99	27.4/4.1	26.7/3.9	21.8 (21.5)	24.3	26.6
Hämeenkyrö-31	10.02.99	21.2/2.5	24.9/3.2	--	--	--
	03.06.99	25.1/3.7	29.4/4.1	22.6 (22.1)	26.2	28.1
Hämeenkyrö-42	11.02.99	22.5/3.0	22.9/2.9	20.9 (20.8)	22.7	26.0
	02.06.99	24.8/3.4	24.4/2.4	22.3 (21.9)	25.4	27.7
Jämsä/	12.02.99	18.5/2.9	--	--	--	--
	03.05.99	21.7/2.5	--	--	--	--

* ***Speeds at the circulatory carriageway were the speeds, recorded through entry and exit points. In the mean speed column the values presented inside the brackets are represents harmonic mean. The another value represents the arithmetic mean of the same speed-data.***

The average speeds at the circulatory carriageway of Category 1 vehicles were between 20.4 – 26.2 km/hour. The values at the entry and exit were respectively in between 18.5 – 29.6 km/hour and 20.5 – 29.4 km/hour. The corresponding values for the Category 2 vehicles were respectively 16.9 - 26.7 km/hour and 19.5 - 27.8 km/hour. At the circulatory carriageway the average speeds of Category 2 vehicles were between 14.5 - 22.7 km/hour.

Table 15: Summary of the analysed speeds both in winter and summer for the vehicles belongs to Category 2.

Location/ Vehicle path curvature, R (m)	Date	Mean speed with st.deviation (km/h)		Speed at the circulatory carriageway (km/h)		
		Entry	Exit	Mean*	V_{85}	V_{max}
Muhos/ 85	02.12.98	23.7/2.9	23.4/2.8	22.7 (22.3)	25.7	28.7
	28.04.99	22.9/3.8	22.6/3.0	21.4 (21.1)	24.0	29
Kaustinen/ 37	19.01.99	24.4/3.3	20.5/1.8	21.0 (20.7)	24.0	29.4
	09.06.99	26.0/3.9	22.8/3.2	20.8 (20.3)	24.2	25.4
Virrat/ 29	20.01.99	--	--	--	--	--
	04.06.99	22.1/3.6	--	18.5 (18.3)	20.5	21.4
Keuruu/ 50	21.01.99	25.8/5.5	22.9/3.9	20.7 (20.2)	24.5	29.0
	07.05.99	24.9/3.7	24.9/3.3	22.7 (22.5)	25.4	29
Hämeenlinna/ -	04.02.99	19.5/3.0	24.4/3.4	--	--	--
	04.05.99	26.7/4.7	25.8/3.1	21.5 (21.1)	24.5	27.8
Hämeenkyrö-2/ 31	10.02.99	19.5/3.5	19.6/2.3	--	--	--
	03.06,99	22.1/3.1	26.1/3.2	21.2 (20.9)	23.8	27.2
Hämeenkyrö-1/ 42	11.02.99	18.6/2.8	19.5/2.5	17.6 (17.5)	19.5	23.0
	02.06.99	24.5/4.1	21.5/2.9	20.1 (19.7)	23.2	27.2
Jämsä/ 29	12.02.99	16.9/3.3	--	--	--	--
	03.05.99	21.2/4.0	22.3/2.3	14.5 (14.4)	15.9	17

* ***Speeds at the circulatory carriageway were the speeds, recorded through entry and exit points. In the mean speed column the values presented inside the brackets are represent harmonic mean. The another value represents the arithmetic mean of the same speeds.***

The vehicle speeds at the entry were affected by the entry deflection. The speeds at the entry among the recorded roundabout on the main road were analysed by using correlation with the entry deflection. The correlation coefficients show that the entry deflection has negative influences in respect of the entry speeds. The entry speeds decreased when the entry deflection increased. The relations between these two factors were stronger in summer than in winter circumstances. *Table 16* shows the correlation coefficients between summer speeds, winter speeds and the entry deflections.

Table 16: Correlation coefficients between summer speeds, winter speeds and entry deflections.

	Speeds in winter		*Speeds in*	
	Category 1	*Category 2*	*Category 1*	*Category 2*
Entry deflection	-0.5900	-0.4959	-0.8697	-0.7016

At the approach there were no difficulties found among the vehicles of both categories. The speeds of approaching vehicles were recorded 50 metres away from the entry point of the roundabouts. At the approach point average speed varied between 36.9 - 45.0 km/hour for Category 1 vehicles and 35.1 - 41.4 km/hour for Category 2 vehicles. The different circumstances in winter and summer did not affect the vehicle speeds remarkably. The only exception was Hämeenlinna, where average speeds increase in summer 6 km/hour for Category 1 and 8 km/hour for Category 2 vehicles. At the approach point most of the drivers drove their vehicles by maintaining speed limit. The drivers of Category 2 vehicles drove at lower speeds than that of the drivers of Category 1 vehicles do. *Table 17* shows the average approaching speeds at different roundabouts in the both winter and summer circumstances.

Speeds at the exit of the roundabout were clearly depending on the speeds at the circulatory carriageway. The observation shows that the average departure speeds were little bit greater than that of average speeds at the circulatory carriageway for the vehicles of both categories. In the summer circumstances speeds at the departure had been found a little higher than that of in the winter circumstances. There were no difficulties found at the departure, which will cause any type of accidents or create dangerous situation at the intersection. But in the winter circumstances there were some difficulties to accelerate vehicles' speeds at the departure. The cause was the accumulated snow, which had made the road surface slippery.

Table 17: The average approaching speeds at different roundabouts.

Location	Approach width (m)	Date	Average speeds	
			Category 1	Category 2
Muhos	4.3	02.12.98	37.7	35.1
		28.04.99	38.9	35.4
Kaustinen	3.6	19.01.99	42.2	40.0
		09.06.99	41.6	39.1
Virrat	4.5	20.01.99	45.0	41.4
		04.06.99	41.5	41.2
Keuruu	5.5	21.01.99	43.5	39.7
		07.05.99	40.1	38.0
Valkeakoskentie	4.3	02.02.99	37.3	--
		06.05.99	36.9	--
Alasentie	4.0	03.02.99	39.1	--
		05.05.99	40.0	--
Hämeenlinna	4.6	04.02.99	37.9	35.6
		04.05.99	43.9	43.6
Hämeenkyrö-2	4.3	10.02.99	39.4	38.1
		03.06.99	43.9	41.2
Hämeenkyrö-1	3.7	11.02.99	37.0	35.6
		02.06.99	40.3	39.2
Jäms	4.6	12.02.99	38.3	38.8
		03.05.99	38.4	38.4
Total average in			40.6	39.5
Total average in			39.7	38.0

5 SURVEY OF HEAVY VEHICLE USE AT ROUNDABOUTS

A total of 120 drivers of heavy vehicles were interviewed for this study at the Hämeenkyrö, Jämsä, Kaustinen and Keuruu roundabouts in late October and early November 1999 (see *Appendix 5* for survey questions). The number of drivers interviewed at each roundabout is given in *Table 18.*

Table 18: Number of drivers interviewed at each roundabout.

ROUNDABOUT	NUMBER OF DRIVERS
Hämeenkyrö	35
Jämsä	35
Kaustinen	35
Keuruu	15

The vehicles were categorised as follows:

I. Trucks without trailers (KAIP),

II. Module combinations (KAM); this also includes other vehicles longer than 24 metres,

III. Truck and trailer combinations (KATP); this also includes semitrailer combinations,

IV. Buses (LA),

V. Other heavy vehicles and vehicle combinations.

5.1 Using roundabouts

Table 19 shows how drivers of different vehicles view driving on roundabouts. The figure in parentheses indicates the percentage of the vehicle category in question. Drivers of module combinations and other truck and trailer combinations seem to be most critical, whereas most drivers of buses and trucks without trailers do not consider roundabouts difficult to negotiate.

Table 19: Using roundabouts, by vehicle category.

VEHICLE CATEGORY	Difficult (%)	Average (%)	Easy (%)	Total
KAIP	1 (5.0)	6 (30.0)	13 (65.0)	20
KAM	6 (40.0)	7 (46.7)	2 (13.3)	15
KATP	20 (30.3)	24 (36.4)	22 (33.3)	66
LA	1 (7.7)	3 (23.0)	9 (69.2)	13
Other	2 (40.0)	1 (20.0)	2 (40.0)	5
Total	30	41	48	119
Total (%)	25.2	34.5	40.3	

5.2 Vehicle paths

The vehicle paths chosen by drivers taking their vehicles straight through roundabouts were examined by showing the respondents the picture in *Appendix 6* and asking them to select the path they normally take. In alternative A, the vehicle first goes near the edge of the central island and then heads right towards the outer edge of the circulatory carriageway. In C the vehicle goes to the right of the circulatory carriageway as soon as it enters the junction, while alternative B provides the driver with the straightest route through the roundabout. All the drivers of module combinations and most drivers of other truck and trailer combinations referred to alternative A, while most drivers of trucks without trailers opted for B. Though alternative C was the most popular choice among bus drivers, A and B, too, enjoyed equal support among them. The vehicle paths taken by drivers of different vehicle categories is shown in *Table 20*. The figure in parentheses indicates the percentage of the vehicle category in question.

Table 20: Vehicle paths taken by different vehicle categories.

VEHICLE CATEGORY	A (%)	B (%)	C (%)	Total
KAIP	1 (5.0)	12 (60.0)	7 (35.0)	20
KAM	14 (100.0)	0	0	14
KATP	44 (67.7)	14 (21.5)	7 (10.8)	65
LA	4 (30.8)	4 (30.8)	5 (38.5)	13
Other	4 (80.0)	1 (20.0)	0	5
Total	67	31	19	117
Total %	57.3	26.5	16.2	

5.3 The biggest problems experienced when negotiating a roundabout

The drivers were also asked about the most serious problems they experience when negotiating roundabouts. Drivers of the heaviest vehicle combinations in particular criticized the lack of space and the kerbing, while bus drivers were unhappy with the behaviour of other drivers (e.g. failure to use indicators properly). Truck drivers complained most about slippery road surfaces in the winter. The drivers' opinions are summarized in *Table 21*. The figure in parentheses indicates the percentage of the vehicle category in question.

Table 21: The biggest problems experienced when negotiating roundabouts, by vehicle category.

Vehicle category	**Lowering speed**	**Changing gear**	**Turning the steering wheel**	**Acceleration after roundabout**	**Lack of space**	**Behaviour of other drivers (e.g. use of indicators)**	**Slippery road conditions**	**Loose or sharp-edged kerbing**	**Total**
KAIP	3 (21.4)			1 (7.1)	1 (7.1)	3 (21.4)	6 (42.9)		14
KAM	1 (7.7)				5 (38.5)	1 (7.7.)	2 (15.4)	4 (30.8)	13
KATP	5 (9.1)	1 (1.8)	2 (3.6)	5 (9.1)	26 (47.0)	6 (10.9)	5 (9.1)	5 (9.1)	55
LA			1 (16.7)	1 (16.7)	1 (16.7)	3 (50.0)			6
Other					3 (75.0)			1 (25.0)	4
Total	9	1	3	7	36	13	13	10	92
Total %	9.8	1.1	3.3	7.6	39.1	14.1	14.1	10.9	

The drivers were also asked to identify the roundabouts that present them with the most serious problems. Hämeenkyrö, Kyröskoski and Kaustinen were usually considered the most difficult ones; in fact all three were mentioned more than 10 times. The drivers named a total of 39 localities which in their opinion have difficult roundabouts, but as one locality can have several roundabouts, drivers may have referred to different junctions in the same locality. In addition to a number of individual roundabouts, criticism was also levelled at places with several successive roundabouts. Problematic localities are listed in *Appendix 7*.

5.4 Kerbs

Sharp-edged or high kerbs at roundabouts can cause problems for heavy vehicles. 49 drivers said that they sometimes hit the kerbing and that sometimes this has resulted in punctured tyres. Such occurrences were most common at the roundabouts which were considered difficult. *Table 22* presents the roundabouts (by vehicle category) at which drivers say they have hit the kerb, while *Table 23* lists the location on the vehicle received the impact. Most commonly this is the rear tyres, which tend to hit the outer kerb slightly more often than in the inner one.

Table 22: Roundabouts at which drivers report hitting kerbs.

Roundabout	**KAIP**	**KAM**	**KATP**	**LA**	**Other**	**Total**
Hämeenkyrö		2	5			7
Juva			1			1
Jämsä	1	2	3			6
Kangasala				1	1	2
Kannus			1			1
Karstula			1		1	2
Kaustinen			8			8
Keuruu				2		2
Kyröskoski	1	1	3	3		8
Lapinlahti			1			1
Mänttä	1	1		1		3
Nummela		1				1
Orivesi			2			2
Oulu			1			1
Sievi		1				1
Säynätsalo			1			1
Turenki		1				1
Vammala			1			1
					Total	49

Table 23: The part of the vehicle hitting the kerbing on the roundabout.

Roundabout	Left front	Left rear	Right rear	Right front	
Hämeenkyrö		4	3		
Juva			1		
Jämsä		3	2		
Kangasala			2		
Kannus			1		
Karstula	1	1			
Kaustinen		3	5		
Keuruu		2			
Kyröskoski	1	1	6		
Lapinlahti		1			
Mänttä		1	2		
Nummela		1			
Orivesi		1	1		
Oulu		1			
Sievi		1			
Säynätsalo			1		
Turenki			1		
Vammala			1		
Total	2	20	26		**48**

NOTE: only one part hitting the kerb is given for each vehicle involved.

5.5 Types of junction

36 of the drivers interviewed preferred signal-controlled junctions to other types of junction. The fact that these have clearer right-of-way rules was one of the reasons. However, a majority (76 drivers) preferred roundabouts, though in this group there were many who viewed them as superior only if they are large enough.

The drivers were also asked to express their opinions about the roundabouts at which the interviews took place. More than half considered them better than average and only 5% thought they were below average. All those in the latter group, however, were generally satisfied with roundabouts. Drivers' views of the roundabouts surveyed are presented in *Table 24*. The figure in parentheses indicates the percentage for the roundabout in question.

Table 24: Drivers' views of the roundabouts surveyed in relation to other roundabouts.

JUNCTION	Better (%)	Average (%)	Worse (%)	Total
Hämeenkyrö	22 (64.7)	11 (32.4)	1 (2.9)	34
Jämsä	12 (35.3)	18 (52.9)	4 (11.8)	34
Kaustinen	21 (60.0)	13 (37.1)	1 (2.9)	35
Keuruu	8 (66.7)	4 (33.3)	0	12
Total	63	46	6	115
Total %	54.80	40.00	5.20	

5.6 Visibility and perceptibility of the roundabouts surveyed

The drivers were also asked about the visibility and perceptibility of the roundabouts surveyed during daylight hours and at night. Their views are given in *Tables 25* and *26.*

Table 25: Visibility and perceptibility of roundabout during daylight hours.

JUNCTION	Good	Poor
Hämeenkyrö	33	2
Jämsä	31	4
Kaustinen	32	1
Keuruu	14	

Table 26: Visibility and perceptibility of roundabout at night.

JUNCTION	Good	Poor
Hämeenkyrö	28	6
Jämsä	28	6
Kaustinen	27	5
Keuruu	13	1

5.7 Driving experience

The respondents were also asked how many years they had been driving heavy vehicles.

Table 27: Driving experience.

Driving experience	Number of drivers
less than 6 years	26
6 - 15 years	24
more than 15 years	69

5.8 Drivers' attitudes towards roundabouts

Of all the drivers interviewed, 62% had a positive attitude towards roundabouts, while 37% took a neutral view and 11% were against. The most positive views were found among bus drivers: 87.5% were satisfied with roundabouts, while the rest took a neutral stand. The most negative attitudes were held by those drivers who considered the negotiation of roundabouts difficult and those who gave preference to signal-controlled junctions. All those with negative views of roundabouts were drivers of the heaviest vehicle combinations (Appendix 8). Driving behaviour had little impact on the opinions. Those whose vehicles had hit kerbs were usually slightly more critical of roundabouts than those without such experiences.

The general views of roundabouts held by drivers with different degrees of experience are given in *Table 28*. It seems that with more driving experience, drivers' attitudes towards roundabouts become slightly more positive.

Table 28: Drivers' attitudes towards roundabouts, according to driving experience.

Driving experience	positive	neutral	negative
less than 6 years	14	10	2
6 - 15 years	12	9	3
more than 15 years	41	21	7
Total	67	40	12

6 SUMMARY AND CONCLUSIONS

This study has evaluated the performance of heavy vehicles at selected Finnish roundabouts. The results show that the roundabouts caused all drivers to reduce their speed. Thus they help the vehicles to pass through the intersection safely to all directions.

The paths taken by the vehicles differed significantly between summer and winter, the paths being closer to the central island in winter than in summer. Most drivers sought to drive their vehicles as straight as possible to avoid the rear part of their vehicle skidding. In winter, the central island kerbing was not visible enough because of the accumulated snow. The path appears to depend on the geometry of the roundabout too. The vehicle paths corresponded with the width of the circulatory carriageway and the curvature of the vehicle path. Among the roundabouts studied, the central island diameter varied between 16 and 40 metres. The bigger the diameter of the central island the lower the speeds of vehicles, due to the deflection of their paths.

At the roundabouts studied the increased deflection of vehicle paths tended to reduce speeds though the diameter of the central island was larger. Vehicle paths were closer to the central island in summer at the Kangasala and Hämeenkyrö roundabouts. The paths were furthest from the central island at the Jämsä roundabout, but the speeds at the circulatory carriageway were lower; the truck apron was a factor in this. At Jämsä the kerb of the truck apron structure was about 5 centimetres high, making it in convenient to drive over it. Vehicles were driven as near the truck apron as possible to pass through the roundabout. The truck apron structures of the roundabouts at Kaustinen and Kangasala (Alasentie) were similar. Though the kerb of the truck apron at Kaustinen was at a slight angle, no one drove over it because it was still raised too much from the road surface. At Alasentie some drivers did drive over the truck apron because the circulatory carriageway is narrower and the path curvature smaller. *Figures 21* and *22* show the structure of the truck apron at the Jämsä and Kaustinen roundabouts.

Figure 21: The truck apron structure at the Jämsä roundabout.

Figure 22: The truck apron structure at the Kaustinen roundabout.

At the entry point average speeds varied were 16.9 - 26.7 km/h for the Category 2 vehicles of and 18.5 - 29.6 km/h for the Category 1vehicles. Lower speeds (below 20 km/h), were found at Jämsä (16.9 km/h), Hämeenkyrö-1, Härkikuja (18.6 km/h), Hämeenkyrö-2, Esso and Hämeenlinna (19.5 km/h) for Category 2 vehicles For Category 1 vehicles, lower speeds (below 20 km/h) were found only at Jämsä (18.5 km/h). These lower speeds were observed only in winter conditions. In some cases the slippery road surface created difficulties braking or to giving way to other road users. Small differences in speeds between summer and winter conditions were found at all the roundabouts. Entry deflection had a positive effect on reducing entry speeds; entry speeds decreased as deflection increased. This effect was more noticeable in summer than in winter. In winter vehicle paths were straighter than in summer because of accumulated snow and winter conditions in general.

Speeds on the circulatory carriageway did not vary significantly between summer and winter. At some roundabouts speeds in summer were a little lower than those in winter. It was difficult for drivers to recognise the edge of the carriageway in winter because of accumulated snow. The lowest speed was 20.4 km/h at the Alasentie roundabout in summer for vehicles Category 1. The lowest speed for Category 2 vehicles was 14.5 km/h at the Jämsä roundabout in the summer. Speeds on the circulatory carriageway were directly correlated to the width and the vehicle path curvature of the circulatory carriageway. Speeds increased when the dimensions of both these parameters increased.

Speeds at the exit of the roundabouts were clearly related to the speeds on the circulatory carriageway. The average speeds at the exit point were a little bit higher than those on the circulatory carriageway; proving that the roundabouts were operating as planned. The speeds at the exit in the summer were a little bit above those in the winter, which was clearly an effect of the slippery road surface.

Roundabouts can effectively relieve unnecessary queuing delay at the intersection. Queuing delay occurs when drivers in the intersecting traffic flow have to wait for a sufficient gap to pass through the junction. In this study 881 roundabout movements by heavy vehicles were investigated. Only 68 vehicles had to come to a complete stop at the entry to the roundabout and 109 had to reduce their speeds below 14 km/h because of the other traffic at the roundabout. At a signal-controlled four-way intersection usually almost the half of the primary traffic flow must stop and both the left-turning flows and the yielding flows must wait in almost every case. Thus roundabouts will generally reduce total delays although in some cases they may increase the delay to the primary flow. Reduced total delays usually lead to better capacity.

Roundabouts therefore appear to operate safely and smoothly. To increase capacity, the following issues should be taken into consideration.

1. At the Hämeenlinna, Kangasala, Kaustinen and Jämsä roundabouts the truck apron is not useable enough. The stones set in the truck apron at Kangasala and Kaustinen could be replaced with other a rough surface treatment. This would help vehicles to drive over them more comfortably and at the same time decrease the chance of car drivers using them. The slope of the truck apron could be steeper than that of the road. It would be best to design truck aprons without using high kerbing. *Figure 23* shows a successful truck apron structure at Hämeenkyrö. Two other examples of successful truck apron structures, from Denmark, are presented in *Figure 24*.

Figure 23: Truck apron structure at the Hämeenkyrö roundabout.

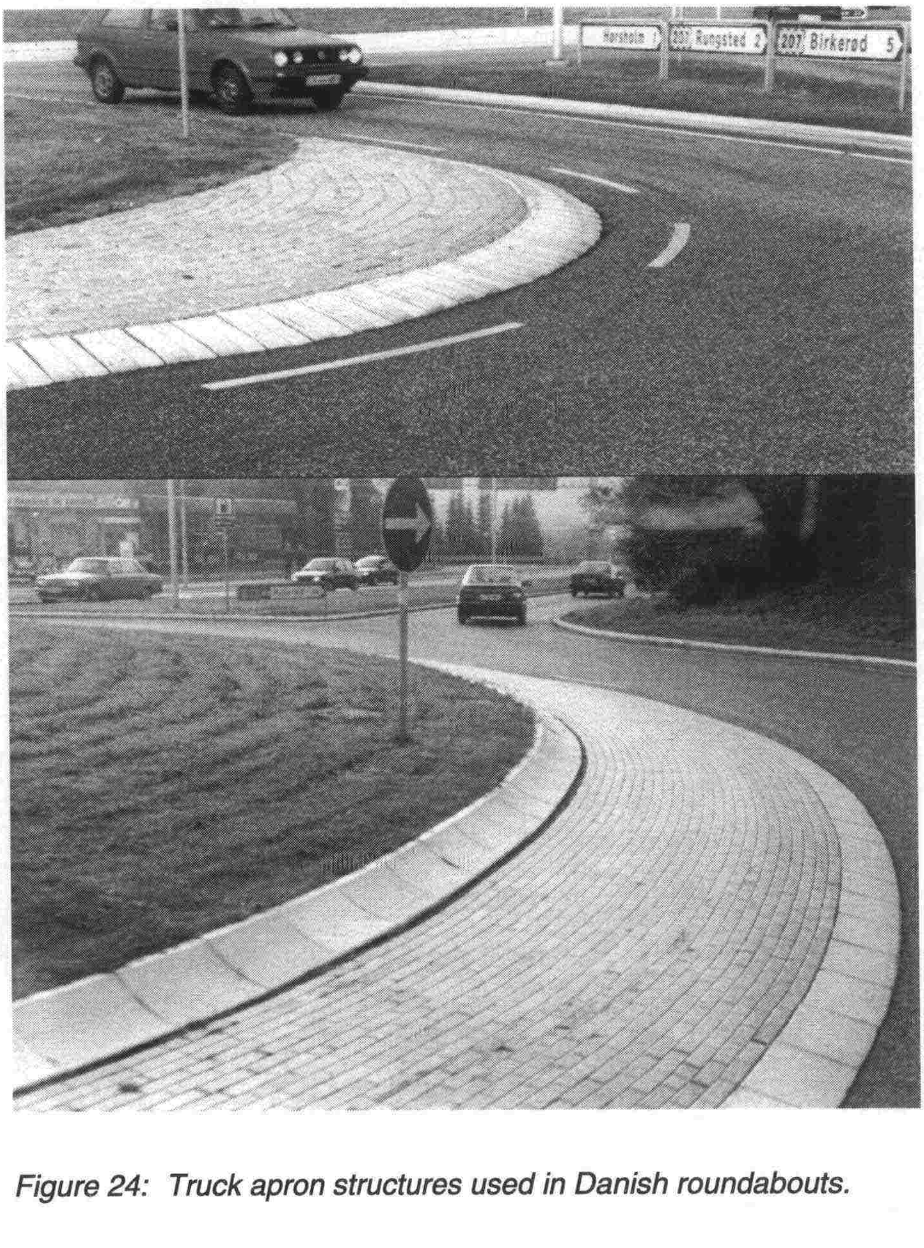


Figure 24: Truck apron structures used in Danish roundabouts.

2. The vehicle path curvature affects speeds as well as driving comfort on a roundabout. Too small (below 35 metres) a path curvature is proved uncomfortable. This may also increase the risk of skidding outwards on the slippery road surface and thus losing control of the vehicle on the circulatory carriageway. Modifications to some elements may improve the situation, such as altering the central island or the truck apron structure. At the Hämeenlinna, Kangasala (Alasentie), Kaustinen and Jämsä roundabouts, the path curvatures could be increased simply by reconstructing the truck apron structures.

3. In winter conditions the visibility and perceptibility were inferior to summer conditions. The main cause was accumulated snow. Better visibility would help drivers to recognise the roundabout from afar. Structural elements should also be easily perceptible so that drivers can be sense where the edges of the roundabout are. Proper lighting and other fixtures would improve the perceptibility of the whole roundabout.

4. Roundabouts should be designed to be easy enough to maintain in winter. If the circulating area is narrow and there is packed snow and ice beside the outer kerbing, this may cause damage to the bumpers of buses. Stones set in the truck apron will tend to collect snow and thus decrease the width of the circulatory carriageway and make the truck apron slippery. They could be replaced with other materials.

5. More attention should be paid to winter maintenance and skid-resistance treatment at the entry, on circulatory carriageway and also at the exit lane. This would help long vehicles to manoeuvre.

6. In some cases roundabouts are not constructed according to the design guidelines (compare *Table 8* and design guidelines). In this study it was found that the circulating area was usually narrower than advised in the design guidelines.

The study concluded that roundabout design is an interactive process that requires practical and engineering skills. This preliminary analysis of the use of roundabouts by heavy vehicles shows that there are differences in the driving behaviour that are related to design details and circumstances. Improving the design can eliminate some of these problems on roundabouts.

Drivers of heavy vehicles seem to be generally satisfied with roundabouts. The most serious difficulties are experienced by drivers of module combinations and other full trailer combinations, whereas drivers of buses and trucks without trailers have fewer problems.

The drivers interviewed were also asked about the path they normally take through a roundabout and could choose from three alternatives: in A, the vehicle first travels near the edge of the central island and then moves right towards the outer edge of the circulatory carriageway. In C the driver moves to the right as soon as he enters the circulatory carriageway, while B offers him the straightest route through the roundabout. Alternative A is the most popular option among drivers of module combinations and other truck and trailer combinations; indeed, in the view of some drivers it is the only way to negotiate narrow roundabouts. All three options found wide support among drivers of buses and smaller vehicles, while drivers of trucks without trailers preferred alternative B, although many of them also used option C.

For bus drivers, the behaviour of other drivers in roundabouts seems to be the most serious problem, while slippery road surfaces in winter present trucks without trailers with the biggest problems. Design aspects, such as kerbs and restricted carriageway width are the factors most heavily criticized by drivers of module combinations and other truck and trailer combinations. Hitting kerbs can result in punctured tyres, and usually it is the rear tyres of the vehicle that receive the impact.

Most drivers interviewed seem to prefer roundabouts to signal-controlled junctions. Those with the opposite view also have a more negative attitude towards roundabouts in general. Negative views could be found among drivers of the heaviest vehicles. Those critical of roundabouts also considered them more difficult to negotiate and named more roundabout-related problems than other drivers. Driving experience hardly had any impact on respondents' views, though it did seem that as drivers acquire more experience, their attitudes towards roundabouts become slightly more positive.

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APPENDICES

1. Rounding of the cab's corner.
2. Location map of the studied roundabouts.
3. A typical vehicle path at the Hämeenlinna roundabout.
4. Cumulative speed distribution curves.
5. Survey of heavy vehicle use at roundabouts.
6. Vehicle paths chosen by drivers at roundabouts.
7. Problematic roundabout localities according to the drivers.
8. Responses of drivers who held negative views about roundabouts.

ROUNDING OF THE CAB'S CORNER

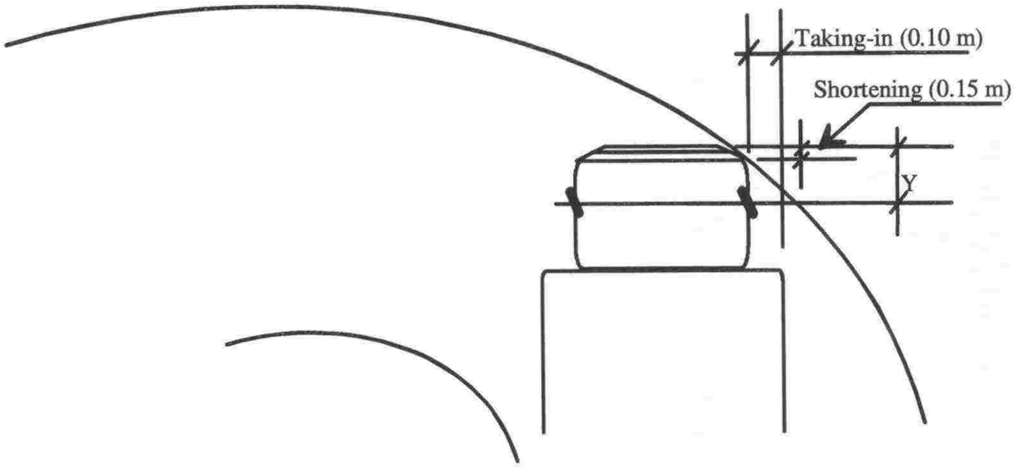


Figure: Rounding and shortening of cab's corner in the circulating carriageway.

LOCATION MAP OF THE STUDIED ROUNDABOUTS

A TYPICAL VEHICLE PATH AT THE HÄMEENLINNA ROUNDABOUT

Figure: *A typical vehicle path from the Hämeenlinna roundabout. The path was straight through the roundabout.*

CUMULATIVE SPEED DISTRIBUTION CURVES

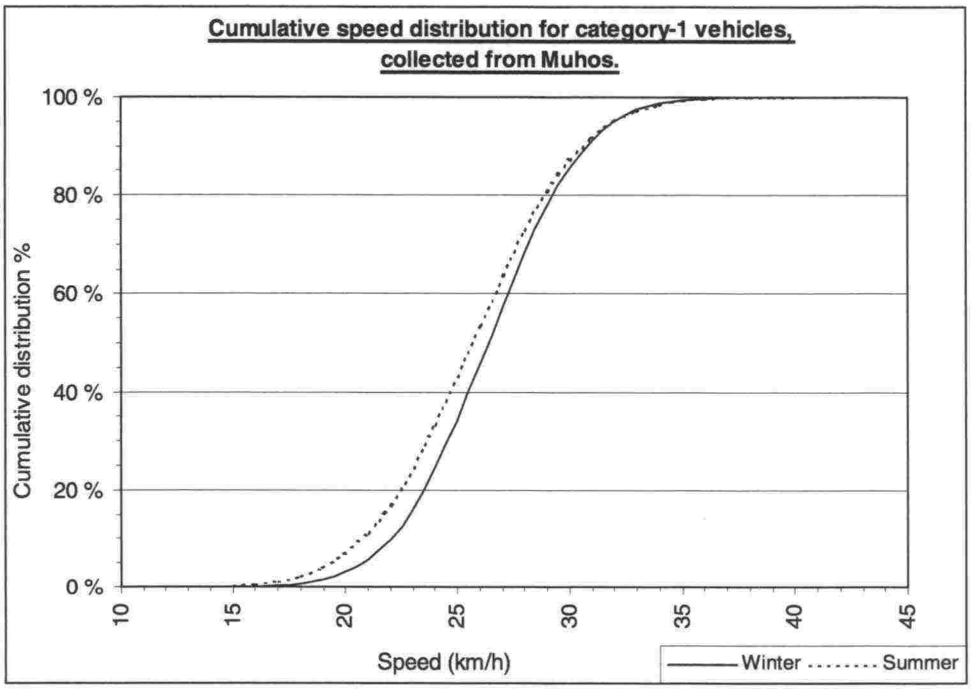


Figure 4.1: Cumulative speed distribution for Category 1 vehicles, collected from Muhos.

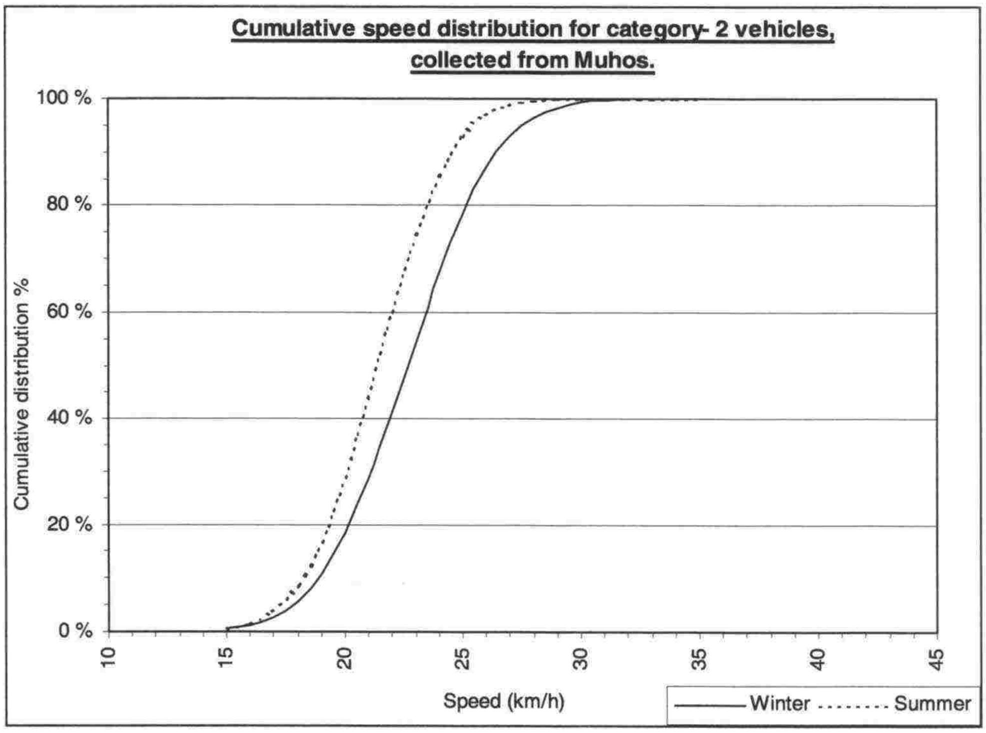


Figure 4.2: Cumulative speed distribution for Category 2 vehicles, collected from Muhos.

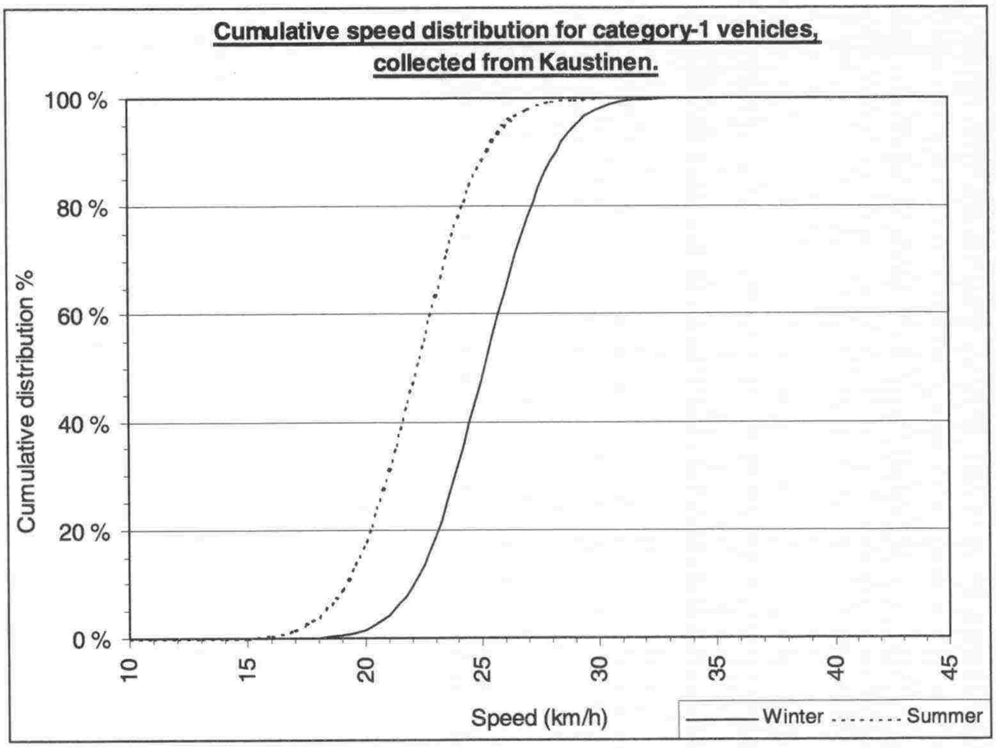


Figure 4.3: Cumulative speed distribution for Category 1 vehicles, collected from Kaustinen.

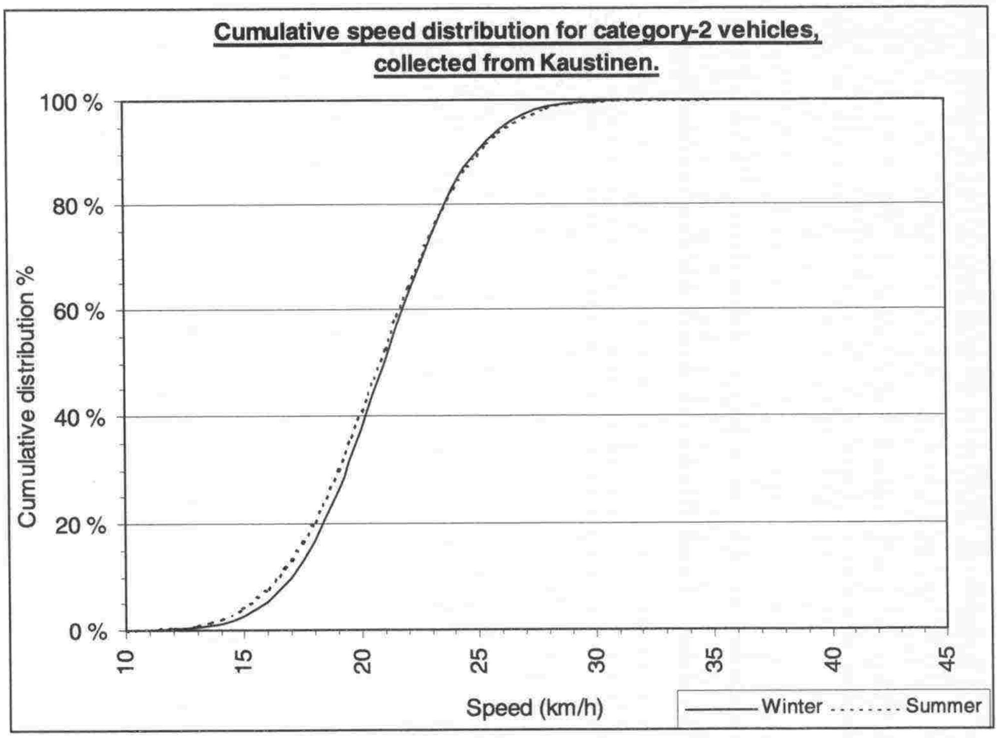


Figure 4.4: Cumulative speed distribution for Category 2 vehicles, collected from Kaustinen.

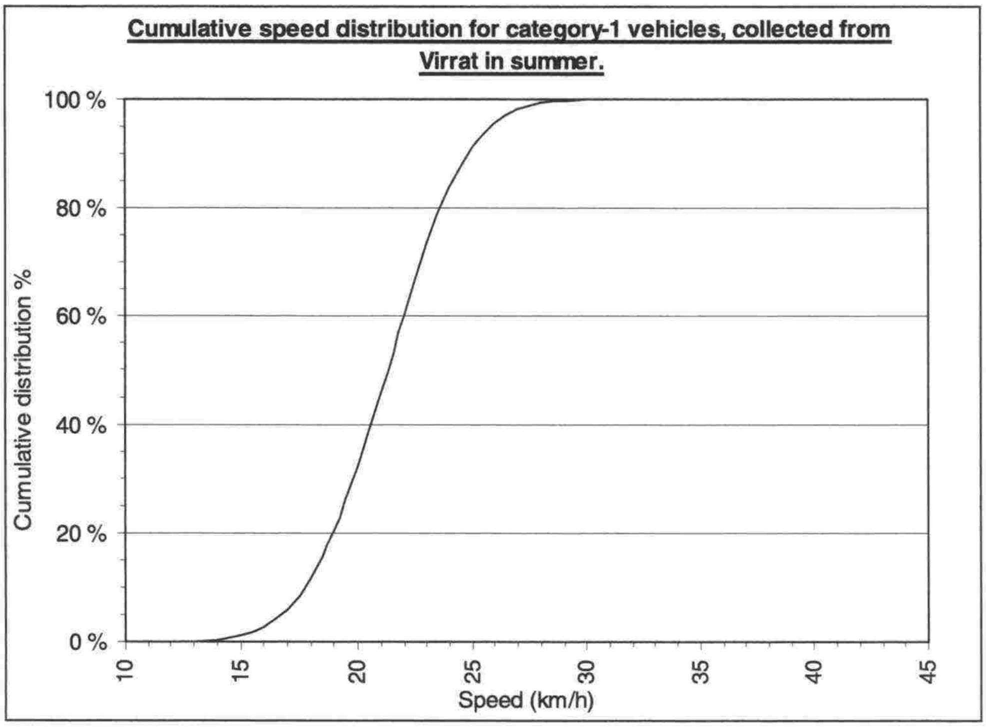


Figure 4.5: Cumulative speed distribution for Category 1 vehicles, collected from Virrat.

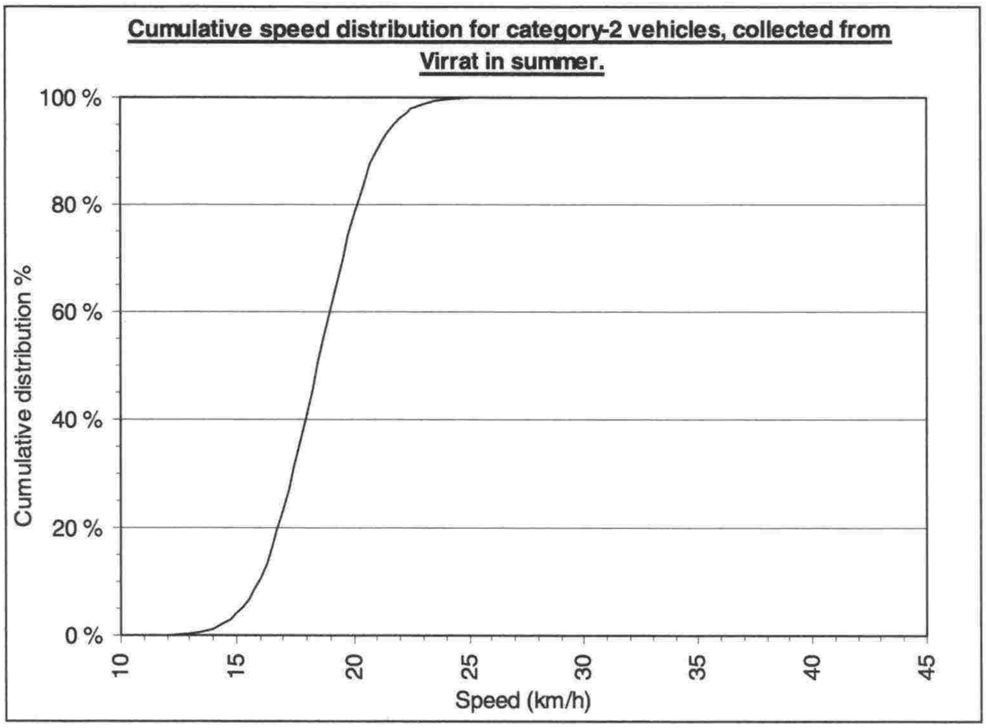


Figure 4.6: Cumulative speed distribution for Category 2 vehicles, collected from Virrat.

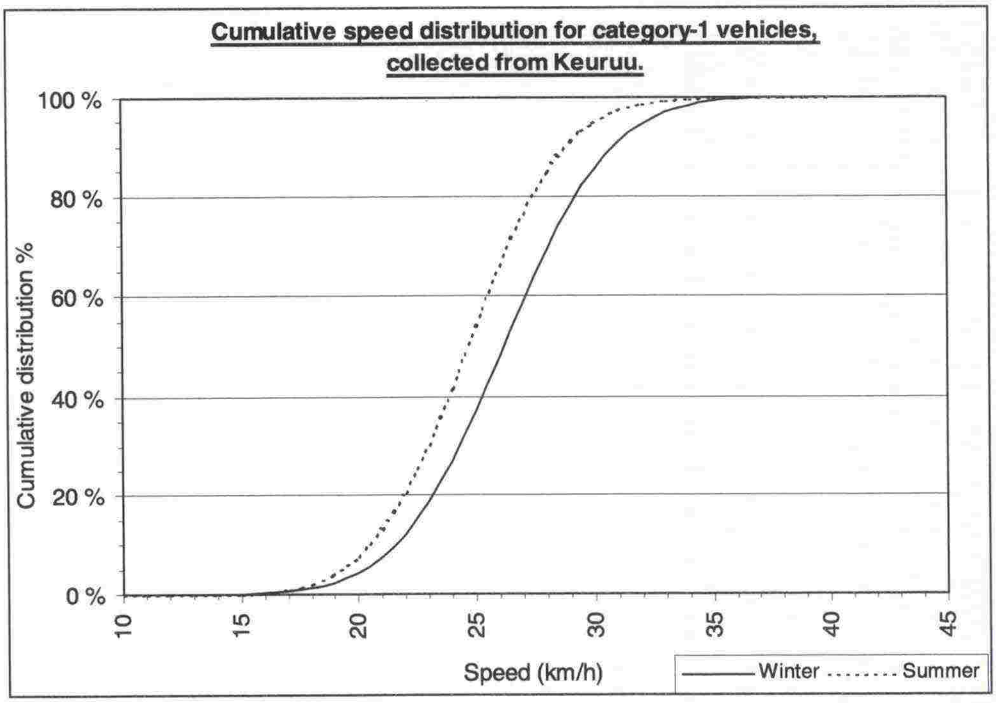


Figure 4.7: Cumulative speed distribution for Category 1 vehicles, collected from Keuruu.

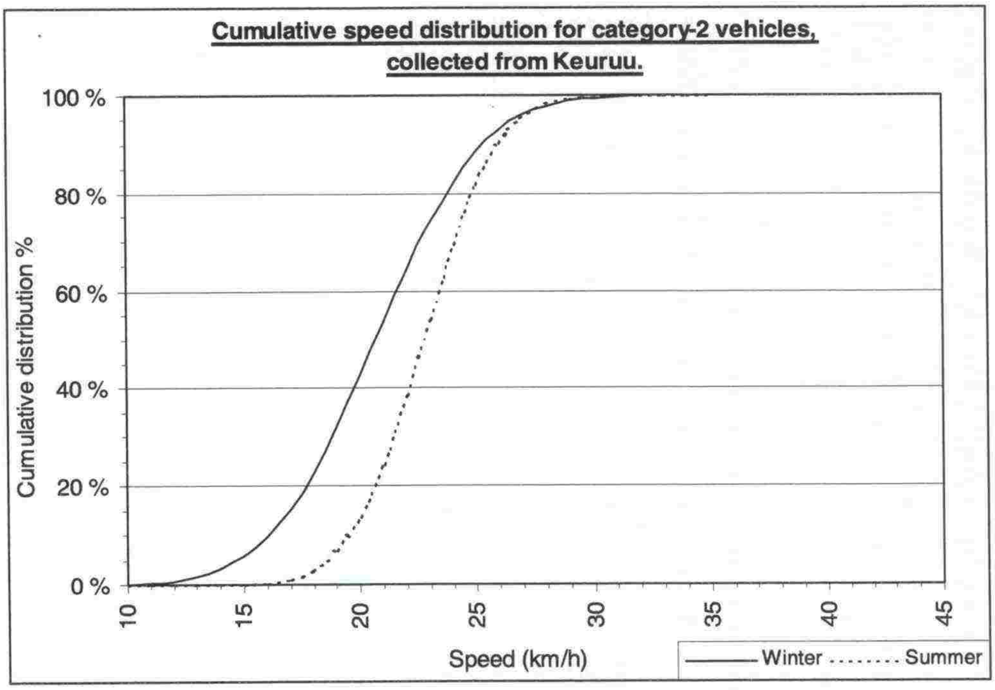


Figure 4.8: Cumulative speed distribution for Category 2 vehicles, collected from Keuruu.

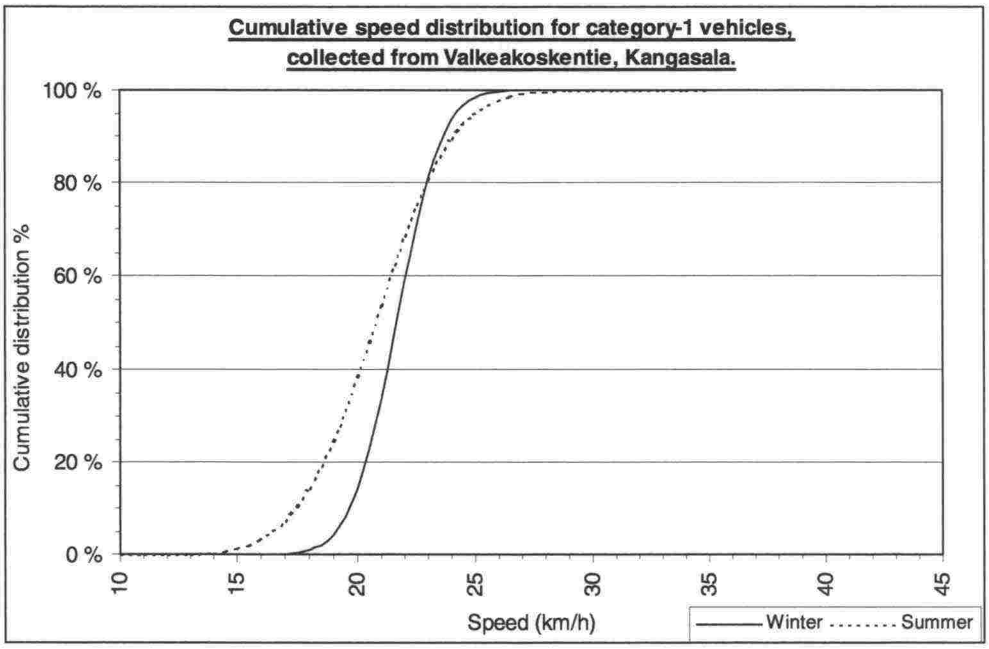


Figure 4.9: Cumulative speed distribution for Category 1 vehicles, collected from Valkeakoskentie, Kangasala.

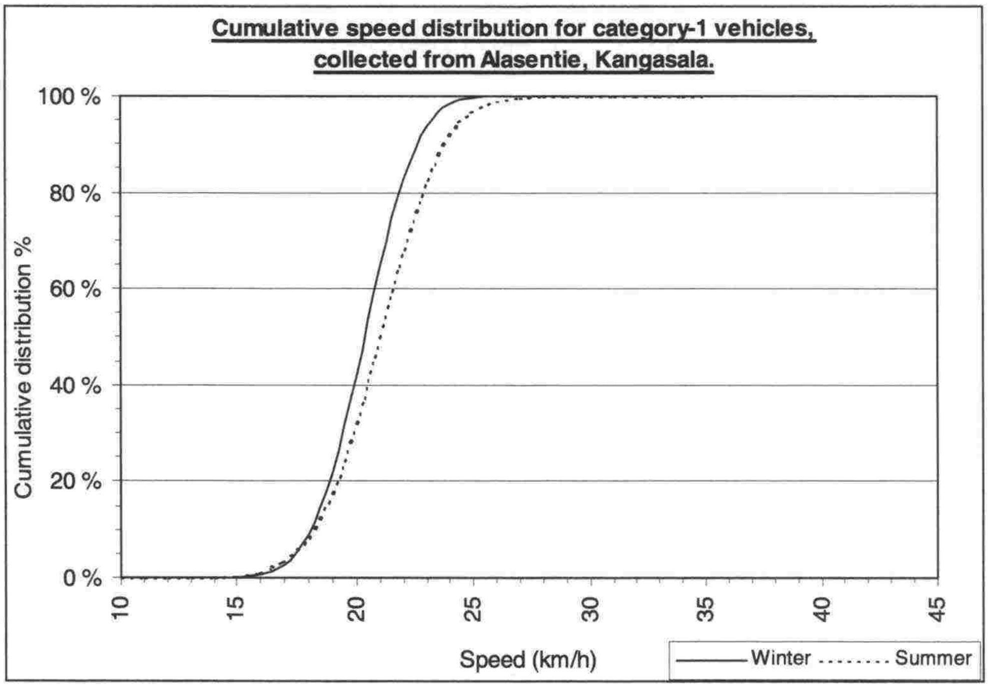


Figure 4.10: Cumulative speed distribution for Category 1 vehicles, collected from Alasentie, Kangasala.

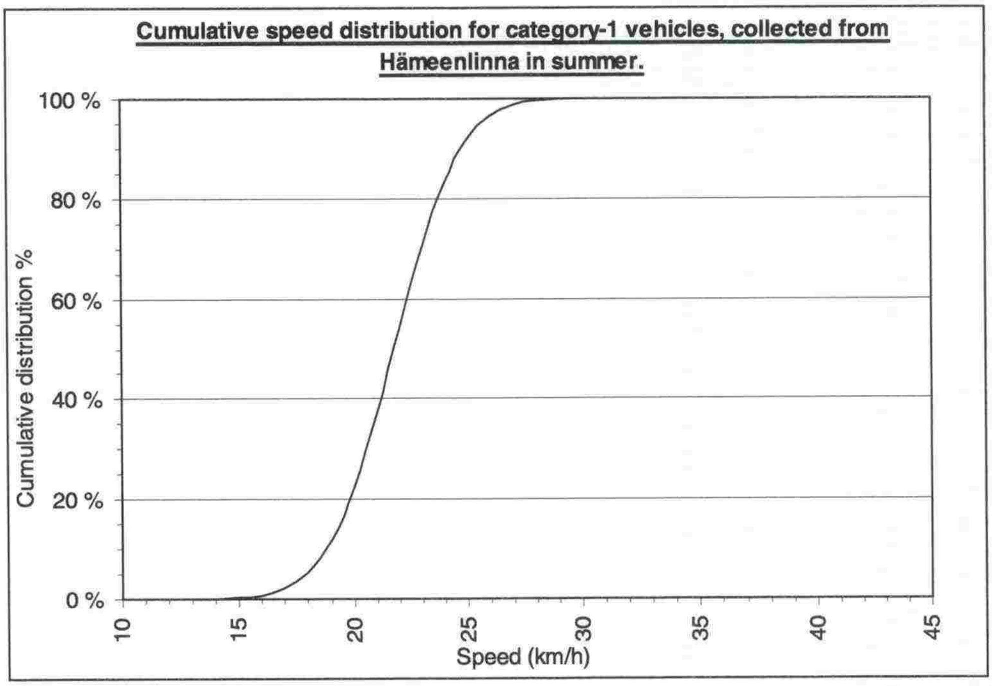


Figure 4.11: Cumulative speed distribution for Category 1 vehicles, collected from Hämeenlinna.

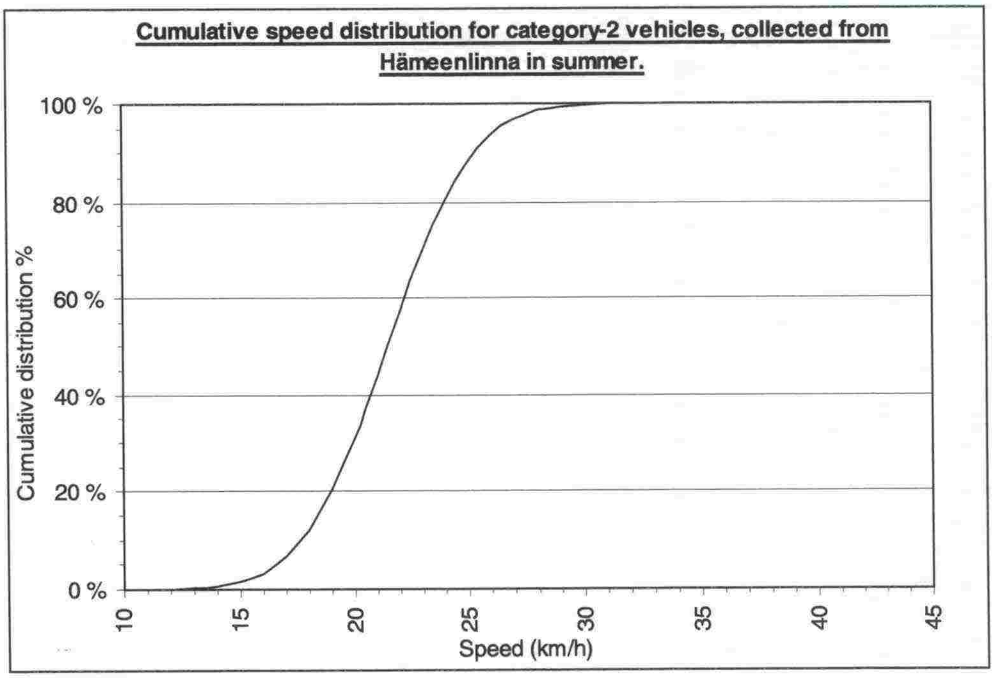


Figure 4.12: Cumulative speed distribution for Category 2 vehicles, collected from Hämeenlinna.

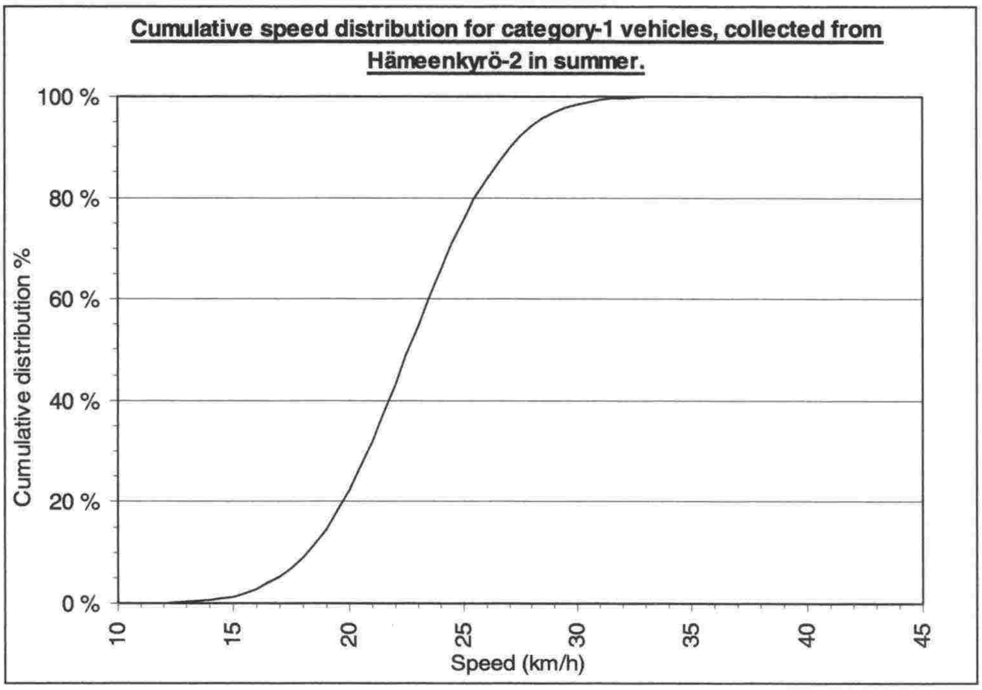


Figure 4.13: Cumulative speed distribution for Category 1 vehicles, collected from Hämeenkyrö-2 (Esso).

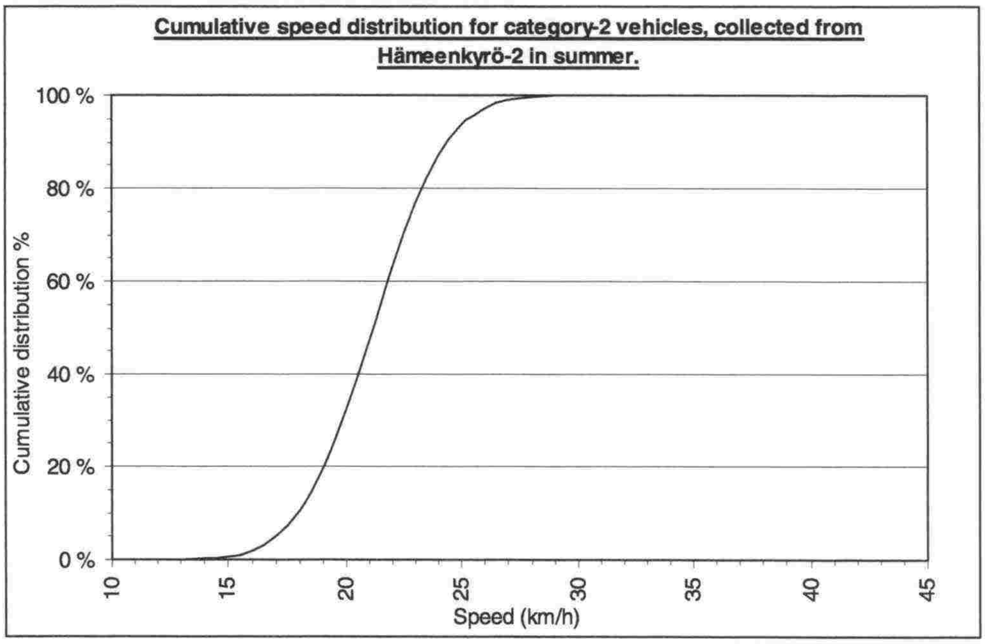


Figure 4.14: Cumulative speed distribution for Category 2 vehicles, collected from Hämeenkyrö-2 (Esso).

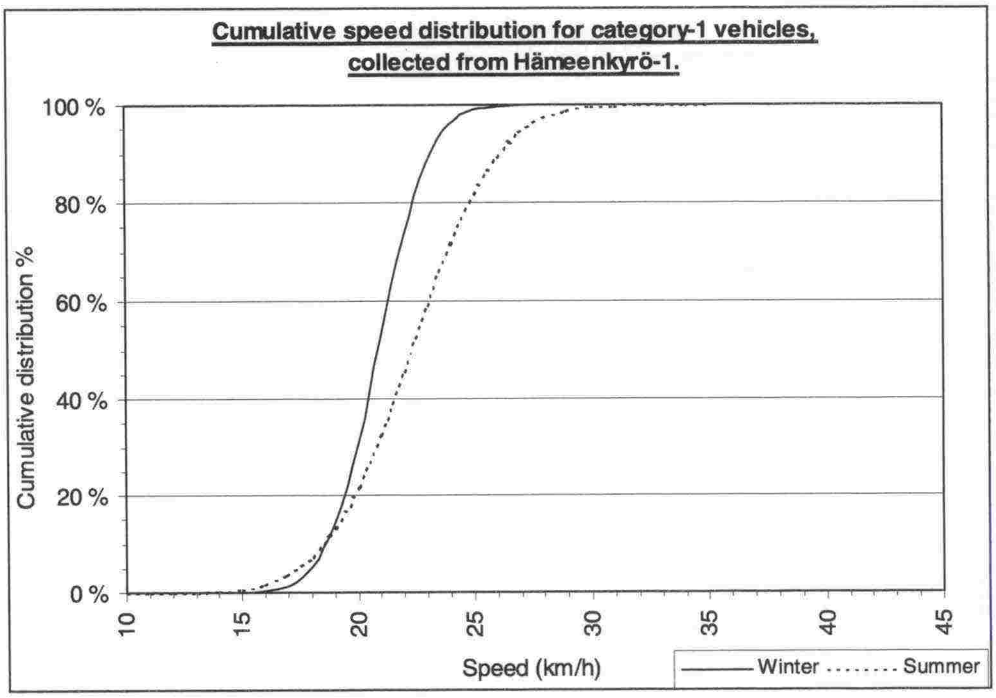


Figure 4.15: Cumulative speed distribution for Category 1 vehicles, collected from Hämeenkyrö-1 (Härkikuja).

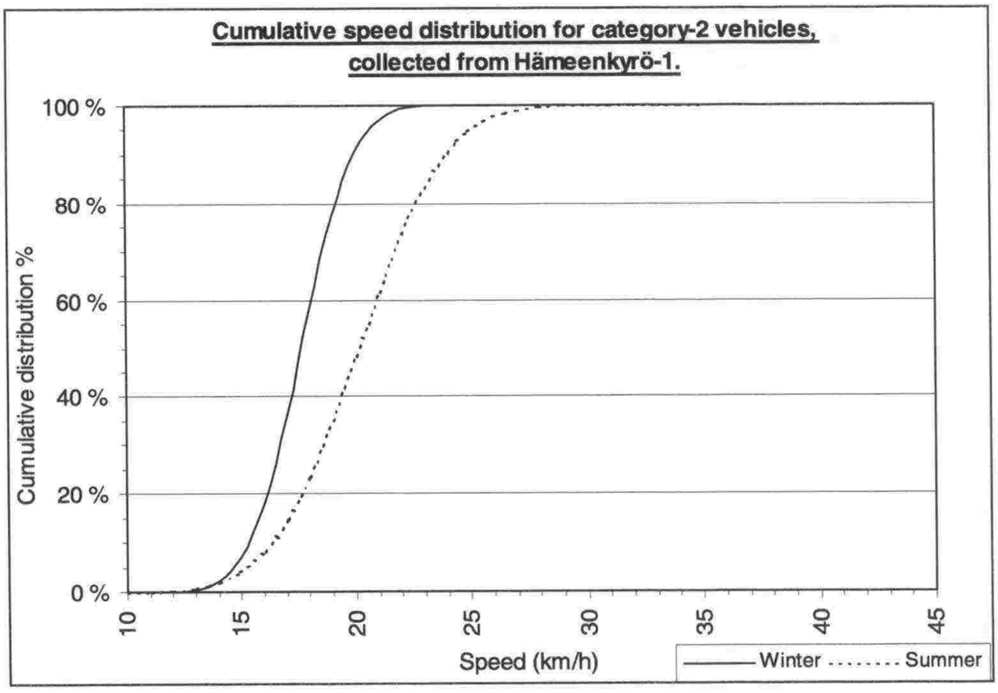


Figure 4.16: Cumulative speed distribution for Category 2 vehicles, collected from Hämeenkyrö-1 (Härkikuja).

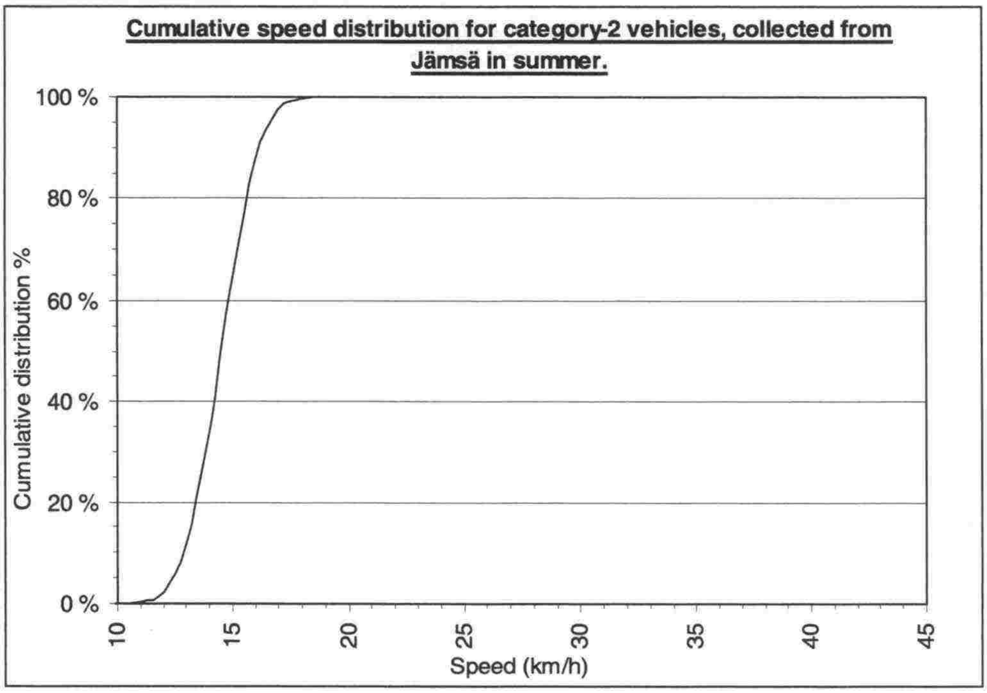


Figure 4.17: Cumulative speed distribution for Category 2 vehicles, collected from Jämsä in summer.

SURVEY OF HEAVY VEHICLE USE AT ROUNDABOUTS

Vehicle category ?

LA ☐ **KAIP** ☐ **KATP** ☐ **Other** ☐

Total lenght of vehicle? **m**

Using roundabouts ? **difficult** ☐ **average** ☐ **easy** ☐

Vehicle path ?

☐ **A** ☐ **B** ☐ **C** ☐ **other**

Name the most problematic roundabouts you have encountered (locality)

Your biggest problem when negotiating a roundabout?

- **reducing speed** ☐
- **changing gear** ☐
- **turning the steering wheel** ☐
- **acceleration after roundabout** ☐
- **other** ☐

Have you ever hit the kerbing? If yes, name the roundabout at which the incident happened

---

Which part of your vehicle received the impact ?

Front ☐ **left** ☐ **right**

Rear ☐ **left** ☐ **right**

Which type of junction do you prefer? ☐ Signal-controlled ☐ roundabout

Is this roundabout better or worse than other roundabouts?

Why? ______________________

____

LA	= Bus
KAIP	= Truck
KATP	= Truck and trailer

Visibility and perceptibility?

During daylight	☐	Good	☐	Poor
At night	☐	Good	☐	Poor

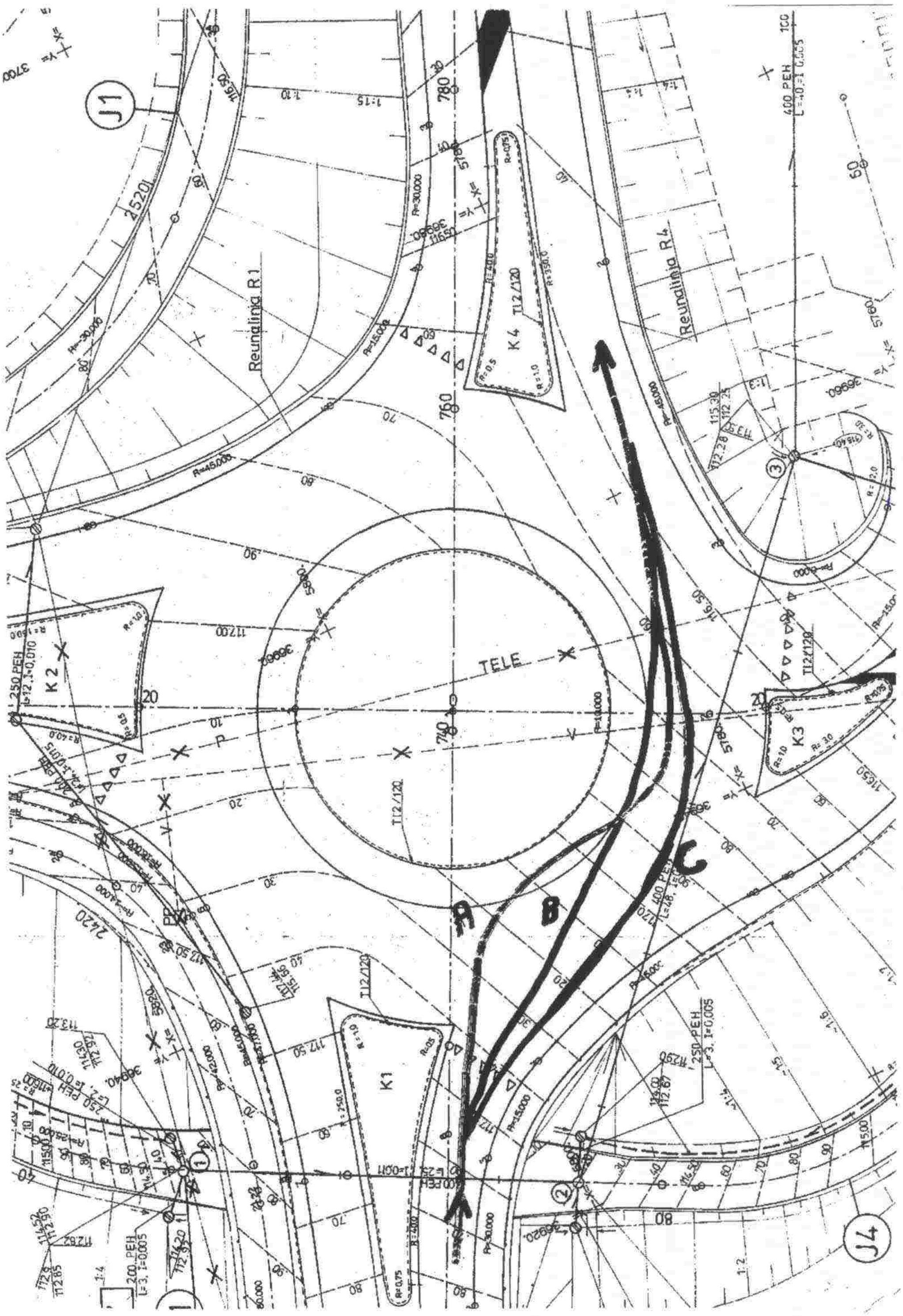
Driving experience?

__________ Years

General attitude towards roundabouts?

☐ positive ☐ neutral ☐ negative

VEHICLE PATHS CHOSEN BY DRIVERS AT ROUNDABOUTS



PROBLEMATIC ROUNDABOUT LOCALITIES ACCORDING TO THE DRIVERS

Locality	**Number of mentions**
Hervanta	1
Hyrylä	1
Hämeenkyrö	14
Hämeenlinna	1
Iisalmi	1
Jaala	1
Juva	2
Jyväskylä	1
Jämsä	7
Jämsänkoski	3
Järvelä	1
Kangasala	8
Kannus	3
Karstula	12
Keuruu	8
Kiikka	3
Kokemäki	1
Kyröskoski	13
Lapinlahti	1
Lappajärvi	1
Mänttä	8
Naantali	1
Nivala	1
Nummela	3
Orivesi	3
Oulu	1
Palokka	3
Pietarsaari	1
Selkäharju	1
Sievi	1
Säynätsalo	1
Tuusula	1
Vammala	1
Viljakkala	2
Vilppula	2
Virrat	1
Ylistaro	3
Äetsä	3

RESPONSES OF DRIVERS WHO HELD NEGATIVE VIEWS ABOUT ROUNDABOUTS

Roundabout	Vehicle category	Total length (metres)	Using roundabouts	Vehicle path?	The most problematic roundabouts (locality)	The biggest problem experienced	Hitting kerb, roundabout	Part of vehicle hit	Preferred type of junction	The junction in question compared with roundabouts in general	Visibility and perceptibility during daylight	Visibility and perceptibility at night	Driving experience (years)	General attitude towards roundabouts
Kaustinen	KATP	24	Average	A	Nummela, Karstula	Lack of space	Yes, -	Left rear	Signal-controlled	Better	Good	Good	31	Negative
Kaustinen	KATP	21	Average	B	Jämsä	Other drivers			Signal-controlled	Better	Good	Good	4	Negative
Kaustinen	KATP	22	Average	A	Lappajärvi, Karstula	Acceleration	Karstula, Lappajärvi	Left rear	Signal-controlled	Average	Good	Good	30	Negative
Kaustinen	KATP	21	Easy	C	Kaustinen	Acceleration	Kaustinen	Right rear	Round-about	Better	Good	Good	22	Negative
Kaustinen	KAMOD	25	Difficult	A	Jyväskylä	Lack of space	Yes, -	Right rear	Round-about	Better	Good	Good	1,5	Negative
Hämeenkyrö	KATP	22	Difficult	A	Hämeenkyrö, Nummela, Kangasala	Acceleration	Hämeenkyrö	Left rear	Round-about	Average	Good	Good	25	Negative
Hämeenkyrö	KATP	19	Easy	C	Juva	Reducing speed				Better	Good	Good	21	Negative
Hämeenkyrö	KATP	24	Difficult	B	Selkäharju, Jämsänkoski	Reducing speed, changing gear, turning the steering wheel, acceleration	Juva		Signal-controlled	Average	Good	Poor	18	Negative
Hämeenkyrö	Other, Low loader trailer	16,5	Difficult	A	Hämeenkyrö	Reducing speed, changing gear, turning the steering wheel, acceleration			Signal-controlled	Better	Good	Good	9	Negative
Hämeenkyrö	KATP	22	Difficult	B	Äetsä	Acceleration, driving in the circulatory carriageway			Signal-controlled	Better	Good	Good	15	Negative
Jämsä	KAMOD	25,2	Average	A	Jämsä	Reducing speed, acceleration, lack of space, slippery road surface, other drivers, kerbing	Jämsä	Right rear	Signal-controlled	Average	Good	Good	6	Negative
Jämsä	KAMOD	25,25	Difficult	A	Hämeenkyrö	Reducing speed, turning the steering wheel, acceleration, slippery road surface	Hämeenkyrö	Left rear	Signal-controlled	Better	Good	Good	20	Negative

ISBN 951-726-624-3
ISSN 0788-3722
TIEL 3200602E